BULLETIN OF THE EARTHQUAKE RESEARCH INSTITUTE,
UNIVERSITY OF TOKYO. Vol. 37, Part 4. December, 1959.

# 東京大学
# 地震研究所彙報

第 37 号　第 4 册

昭和 34 年 12 月

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*The Bulletin is published quarterly. (Vols. 1-6 were published at irregular intervals and Vol. 7 consisted of three parts.)*
*Supplementary Volume is published at irregular interval.*

*The authors of the papers alone are responsible for the statements and opinions contained in their respective papers.*

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BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 37 (1959), pp. 545-570

# 35. The Anomalous Behaviour of Geomagnetic Variations of Short Period in Japan and Its Relation to the Subterranean Structure. The 9th report.

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(Read July 21, 1959.—Received July 21, 1959.)

## Summary

The possible cause of the anomaly of short-period geomagnetic variations as observed in Japan is examined in detail. The only way to account for such an anomaly seems to assume a high conducting circuit of roughly elliptical shape, about 200 *km* and 1000 *km* in width and length respectively. Both the ends of the circuit are to be connected with the conducting part of the earth's mantle, while a low conducting cut is also required between the connecting points. The model thus supposed seems to harmonize very well with the anomaly of another sort found in the cases of *Sq* and *Dst*.

A study on the electromagnetic induction within a spherical sheet having a non-conducting hole is also made in order to examine the influence of the sea. It turns out that the Japanese anomaly is hardly ascribed to the effect of the electric currents induced in the sea.

## 1. Introduction

The anomaly of short-period geomagnetic variations, that have been frequently reported in this bulletin[1),2),3),4)] and elsewhere[5),6)], is thought to be caused by induced electric currents flowing in a circuit beneath Japan. Although no close account has been taken of such a high conducting circuit so far, it seems unlikely that we may have any other

1) T. RIKITAKE, I. YOKOYAMA and Y. HISHIYAMA, *Bull. Earthq. Res. Inst.*, **30** (1952), 207, **31** (1953), 19, 89, 101 and 119.

2) T. RIKITAKE and I. YOKOYAMA, *Bull. Earthq. Res. Inst.*, **33** (1955), 297.

3) T. RIKITAKE, I. YOKOYAMA, S. UYEDA, T. YUKUTAKE and E. NAKAGAWA, *Bull. Earthq. Res. Inst.*, **36** (1958), 1.

4) T. RIKITAKE, S. UYEDA, T. YUKUTAKE, I. TANAOKA and E. NAKAGAWA, *Bull. Earthq. Res. Inst.*, **37** (1959), 1.

5) T. RIKITAKE and I. YOKOYAMA, *Journ. Geomagn. Geoelectr.*, **5** (1953), 59.

6) T. RIKITAKE and I. YOKOYAMA, *Naturwissenschaften*, **41** (1954), 420.

alternative by which the observed anomaly can be explained satisfactorily.

The main aim of this paper is to examine the possibility of the supposed circuit as closely as possible. In Section 2, first of all, the writer studies the magnetic effect of a conductor embedded in the non-conducting earth. It becomes clear that no such conductor can produce magnetic fields which account for the anomaly so long as the electromagnetic induction in an isolated conductor is concerned.

The next possibility, that is examined in Section 3, is the branch circuit which is connected to the conducting part of the mantle below the depth of about 400 *km*. If the circuit forms a suitable loop underneath Japan, it might be possible to expect strong electric currents flowing in the circuit provided a sufficient electric potential difference appears between the two connecting points by the electromagnetic induction within the conducting mantle. It turns out, however, that, corresponding to an inducing field of 100 *gammas*, an induced field amounting to only a few *gammas* would be possible by the procedure considered.

The easiest way to increase the induced field would be to suppose a non-conducting cut between the connecting points as is investigated in Section 4 on the basis of a two-dimensional model experiment. By adopting such a configuration of insulator, it is shown that an induced field as large as the inducing one can be expected at the central part of the circuit.

In Section 5 is studied the electromagnetic induction within a spherical sheet having a non-conducting hole. This is useful for studying the influence of the electric currents induced in a sea surrounding a land mass on geomagnetic variations. The view that the anomaly of geomagnetic variations in Japan seems unlikely to be caused by the effect of the sea is also supported by the investigation.

## 2. Magnetic fields produced by electric currents induced within a conductor embedded in the earth

In the previous papers, it has often been pointed out that the anomalously large amplitude of the vertical component, which is observed in the central part of Japan at the time of short-period geomagnetic variations, cannot be explained as the magnetic field produced by the electric currents induced within a circuit which is isolated from the conducting region below the depth of 400 *km*. On this point, however, some further examinations will be made in this section.

Let us suppose that a spherical conductor of radius $a$ is embedded in the earth which is regarded as non-conducting. If we further suppose a uniform magnetic field changing with a time-factor $e^{i\alpha t}$, the magnetic potential of the field can be written as

$$W_e = rHP_1(\cos\theta)\,, \tag{1}$$

where $H$ is the intensity of the field. The time-factor is removed from the expression. It is assumed that the field is directed to the $\theta=0$ direction. The spherical polar coordinates $r$, $\theta$ and $\phi$ are taken here, the origin being taken at the centre of the sphere considered.

The magnetic potential of the field produced by the electric currents induced in the sphere by the uniform field is easily obtained as[7]

$$W_i = a^3 r^{-2} I(i\alpha) HP_1(\cos\theta)\,, \tag{2}$$

$$I(i\alpha) = \frac{1}{2}\left(1 - \frac{F_1(ka)}{F_0(ka)}\right)\,, \qquad k^2 = 4\pi\sigma i\alpha\,, \tag{3}$$

where $\sigma$ denotes the electrical conductivity of the sphere and the magnetic permeability is assumed as unity, while the functions $F_0$ and $F_1$ are given as

$$F_0(x) = \frac{\sinh x}{x}\,, \qquad F_1(x) = \frac{3}{x^2}\left(\cosh x - \frac{\sinh x}{x}\right)\,. \tag{4}$$

From (2), it is easily seen that the induced field can be expressed as that of a magnetic dipole, the axis of which being directed to the $\theta=0$ direction and the magnetic moment being specified by $M$ which is given as

$$M = a^3 I(i\alpha) H\,. \tag{5}$$

For a perfectly conducting sphere, it has been readily shown that $I=1/2$, so that

$$\lim_{\sigma\to\infty} M = \frac{1}{2} a^3 H\,. \tag{6}$$

Assuming various values for $\sigma$, $a$ and the period of variation, modulus of $M$ is calculated as shown in Table 1, where $H$ is always taken as 100 *gammas*.

7) S. CHAPMAN and J. BARTELS, *Geomagnetism* Ch. 12 (1940).

Table 1.

Table 1-1. $a=2\,km$

| $T$ | $\sigma$ (e.m.u.) | | |
|---|---|---|---|
| | $10^{-12}$ | $10^{-10}$ | $\infty$ |
| 1 *min.* | $1.4\times10^{10}$ | $1.4\times10^{12}$ | $4.0\times10^{12}$ |
| 1 *hour* | $2.3\times10^{8}$ | $2.3\times10^{10}$ | 〃 |
| 2 | $1.2\times10^{8}$ | $1.2\times10^{10}$ | 〃 |
| 6 | $3.8\times10^{7}$ | $3.8\times10^{9}$ | 〃 |
| 12 | $1.9\times10^{7}$ | $1.9\times10^{9}$ | 〃 |
| 24 | $9.6\times10^{6}$ | $9.6\times10^{8}$ | 〃 |

Table 1-2. $a=20\,km$

| $T$ | $\sigma$ (e.m.u.) | | |
|---|---|---|---|
| | $10^{-12}$ | $10^{-10}$ | $\infty$ |
| 1 *min.* | $1.4\times10^{15}$ | $3.6\times10^{15}$ | $4.0\times10^{15}$ |
| 1 *hour* | $2.3\times10^{13}$ | $1.7\times10^{15}$ | 〃 |
| 2 | $1.2\times10^{13}$ | $1.1\times10^{15}$ | 〃 |
| 6 | $3.8\times10^{12}$ | $3.7\times10^{14}$ | 〃 |
| 12 | $1.9\times10^{12}$ | $1.5\times10^{14}$ | 〃 |
| 24 | $9.6\times10^{11}$ | $1.5\times10^{14}$ | 〃 |

Table 1-3. $a=100\,km$

| $T$ | $\sigma$ (e.m.u.) | | |
|---|---|---|---|
| | $10^{-12}$ | $10^{-10}$ | $\infty$ |
| 1 *min.* | $4.2\times10^{17}$ | $4.9\times10^{17}$ | $5.0\times10^{17}$ |
| 1 *hour* | $7.4\times10^{16}$ | $4.3\times10^{17}$ | 〃 |
| 2 | $3.9\times10^{16}$ | $4.1\times10^{17}$ | 〃 |
| 6 | $1.8\times10^{16}$ | $3.5\times10^{17}$ | 〃 |
| 12 | $5.0\times10^{15}$ | $3.0\times10^{17}$ | 〃 |
| 24 | $3.2\times10^{15}$ | $2.3\times10^{17}$ | 〃 |

Table 1-4. $a=200\,km$

| $T$ | $\sigma$ (e.m.u.) | | |
|---|---|---|---|
| | $10^{-12}$ | $10^{-12}$ | $\infty$ |
| 1 *min.* | $3.6\times10^{18}$ | $4.0\times10^{18}$ | $4.0\times10^{18}$ |
| 1 *hour* | $1.7\times10^{18}$ | $3.7\times10^{18}$ | 〃 |
| 2 | $1.1\times10^{18}$ | $3.6\times10^{18}$ | 〃 |
| 6 | $3.7\times10^{17}$ | $3.4\times10^{18}$ | 〃 |
| 12 | $1.5\times10^{17}$ | $3.1\times10^{18}$ | 〃 |
| 24 | $1.5\times10^{17}$ | $2.8\times10^{18}$ | 〃 |

In an analysis[1] of the polar magnetic storm that occurred on June 19, 1936, it was shown by T. Rikitake and others that, the anomalous distribution of the induced field can be approximated roughly by the magnetic field of a dipole situated at a depth of 150 *km* in the central part of Japan, the magnetic moment having been estimated at $8.6\times10^{18}$ *e.m.u.* at the maximum of the change. On the basis of this study, H. J. Lippmann[8] concluded that the anomaly of short-period geomagnetic variations as observed in Japan can be interpreted as the effect of the induced field within a spherical conductor having a radius of 130 *km* and a conductivity of $1\Omega^{-1}m^{-1}$ ($=10^{-11}$ *e.m.u.*). He assumed a uniform inducing field of 100 *gammas* with a period of 1 *hour*. In that case, the moment of the induced dipole amounts to $10^{18}$ *e.m.u.* as can be also seen in Table 1.

It seems to the writer, however, that Lippmann's conclusion is hardly acceptable from various considerations which will be examined one by one in the following. First of all, the inducing field at the time of

8) H. J. LIPPMANN, *Zeits. f. Geophys.*, **24** (1958), 113.

the polar magnetic storm concerned amounts to only 30 *gammas* in the vicinity of Japan. It is therefore required to suppose a spherical conductor larger than Lippmann's one. In order to account for the magnetic moment amounting to $8.6\times10^{18}$ *e.m.u.*, a spherical conductor of nearly 400 *km* in radius must exist under Japan, while its conductivity is of the order of $10^{-12}$ *e.m.u.* or higher. It seems unlikely that such a large conducting region really exists beneath Japan. If it existed, that region would be of high temperature and might be probably detected by some other geophysical methods such as by investigation of seismic waves.

On carefully examining Table 1, we should also pay attention to the fact that the moments of the induced dipole for long-period variations do not differ much from those for short-period ones in case the conductivity is high and the radius is large. If $\sigma=10^{-10}$ *e.m.u.* and $a=100$ *km*, for example, the magnetic moment for a 24-*hour* variation amounts to a half of that for a 1-*hour* variation. The fact suggests that, if we have a conductor of the size and conductivity underneath Japan, there should be observed an anomaly of similar sort even in the case of *Sq* field. However, close examination of *Sq*[9] in Japan as well as *Dst*[4] proved that these slower variations behave quite differently, so that it is not conceivable to suppose such an underground conducting mass beneath Japan.

One more objection arises from the fact that the anomaly is observed mainly in the vertical component. In the middle latitude, the magnetic vector for geomagnetic bays or polar magnetic storms lies in a nearly horizontal plane. If there is an underground spherical conductor, the apparent magnetic dipole induced should be also directed to an approximately horizontal direction, so that the induced magnetic field right up the sphere should predominate in the horizontal direction. In the central part of the anomalous area, however, the vertical amplitude of geomagnetic variations is usually equal to the horizontal one. Hence, the spherical conductor model does not account for the observed fact.

Since the spherical conductor model failed, we shall then consider a ring-shape conductor as an alternative. If a circular circuit is placed in a uniform periodic magnetic field which is normal to the circuit, the complex intensity of the electric current induced in the circuit is given by

$$RJ=-i\alpha\pi A^2H-i\alpha LJ\,, \qquad (7)$$

where $R$, $J$, $\alpha$, $A$, $H$ and $L$ denote respectively electric resistance of

9) T. RIKITAKE, I. YOKOYAMA and S. SATO, *Bull. Earthq. Res. Inst.*, **34** (1956), 197.

the circuit, intensity of the induced electric current, angular frequency, radius of the circuit, intensity of the inducing magnetic field and self-inductance of the circuit. If the circuit is composed of a circular wire and its radius is $\rho$, the self-inductance is given by

$$L=4\pi A\left(\log_e \frac{A}{\rho}+0.33\right). \tag{8}$$

Suppose $\rho=10\,km$, $L$ is estimated as $5.5\times10^{9}$ and $5.5\times10^{11}\,cm$ respectively for $A=100$ and $1000\,km$. If we take the electrical conductivity ($\sigma_1$) of the material composed of the circuit to be $10^{-12}\,e.m.u.$ (that is the conductivity below the level of $400\,km$ for the normal part of the earth), $R$ is obtained as $2.0\times10^{9}$ and $2.0\times10^{11}\,e.m.u.$ respectively. If we further assume a period of $1\,hour$, $L/R$ is estimated as $4.8\times10^{-3}$ both for $A=100$ and $1000\,km$. In that case, the second term of the righthand-side of (7) may be ignored, so that, assuming $H=100\,gammas$ as before, we obtain

$$J=0.27\,e.m.u.=2.7\,amp. \tag{9}$$

for both the cases.

At the centre of the circular circuit, the magnetic field produced by the induced current is given by

$$H_i=\frac{2\pi J}{A}. \tag{10}$$

Adopting the value of $J$ in (9), $H_i$ becomes 0.017 and 0.0017 *gammas* for $A=100$ and $1000\,km$. Even if we take $\sigma_1=10^{-10}\,e.m.u.$, $H_i$ does not exceed 2 *gammas*. It then turns out that the induced current produces extremely small magnetic fields, while the observed anomaly of the induced field amounts to the same order as the inducing field. It is then impossible to ascribe the anomaly to the induced current in a ring-shape circuit supposed in the above.

### 3. Branch circuit connected to the conducting part of the earth's mantle

The quantitative study on the magnetic effect of a spherical or ring-shape conductor embedded in the earth confirms the previous view that the electric currents which are responsible for the magnetic anomaly

observed must come from farther depths where the conductivity is believed to be high. One of the most straightforward ways of accounting for the anomaly would be to suppose a branch circuit, both the ends of which are connected to the conducting part of the earth's mantle. If the circuit forms a loop in a suitable way underneath Japan, a part of the electric currents induced in the mantle might flow along the loop and produces a fairly strong magnetic field near the centre of the loop. It has been the only way of explaining the anomaly to suppose such a hypothetical circuit though no exact account has been so far taken of the circuit.

It is the purpose of this section to examine quantitatively to what extent the anomaly may be explained by the branch circuit hypothesis. Let us suppose that the ends of the circuit are connected to the conducting mantle at two points 1000 *km* apart. Although this figure is taken arbitrarily, it would be unlikely to suppose that it is larger or smaller than 1000 *km* by a factor 5 judging from the area of anomaly. Now we are in a position to estimate the electric potential difference between the two points when electric currents are induced in the conducting mantle by geomagnetic variations arising from outside the earth.

For the present study the earth may be regarded as a uniform conductor covered by a non-conducting layer of 400 *km* in thickness. If a uniform conducting sphere of radius $a$ is placed in a uniform time-dependent magnetic field directed to the $\theta=0$ axis, the electric field induced in the sphere has only the azimuthal component which is given as[7]

$$E=\frac{i\alpha}{2}\frac{F_1(ka)}{F_0(ka)}rH\frac{dP_1}{d\theta}\,, \tag{11}$$

where $\alpha$ is derived from the time factor $e^{i\alpha t}$ and $F_0$ and $F_1$ are defined by (4).

Table 2.

| Period | Electric field intensity | Potential difference between the two points 1000 *km* apart |
|---|---|---|
| 1 *h* | 12.4 *e.m.u./cm* | 12.4 *volt* |
| 2 | 8.74 | 8.74 |
| 6 | 5.02 | 5.02 |
| 12 | 3.56 | 3.56 |
| 24 | 2.48 | 2.48 |

At $r=a$ ($a=6000\,km$), modulus of the coefficient of $dP_1/d\theta$ is calculated for various periods as shown in Table 2, while the electrical conductivity is assumed as $2\times10^{-12}\,e.m.u.$ as has been obtained by the present writer[10] previously and the intensity of the inducing field is taken as 100 *gammas*.

The voltage between the two points 1000 *km* apart on the same latitude circle is given in the third columm of the table. The figures, however, should be multiplied by $dP_1/d\theta$ in order to get the actual voltage. Since $dP_1/d\theta$ is not largely different from unity in middle and low latitudes, we may assume that the induced voltage will be of the order as given in the table.

On the basis of the voltage thus estimated, we are going to estimate what amount of electric current will flow in the branch circuit considered. Strictly speaking, the problem should be solved by applying the electromagnetic induction theory to a spherical conductor having the branch circuit. Unfortunately, however, no exact study of such a case is possible in the framework of existing electromagnetic induction theory. We are, therefore, obliged to proceed with an approximate method as will be developed in the following.

The branch circuit forms a closed circuit together with the superficial part of the conductor. We may, however, ignore the voltage which is induced in the circuit by the varying magnetic field, because what we have been dealing with in the final part of the last section suggests that the voltage induced in such a circuit would be extremely small for possible dimensions. Although the actual configuration of the circuit is not known, it does not seem likely that the above presumption changes largely.

From the above consideration, we may treat the matter as if quasi-steady flow of electric currents in the circuit driven by the potential difference between both the ends. The potential difference has been given in Table 2 for respective periods. It is impossible to estimate exactly the electric resistance of the circuit. But we may presume from the discussion of the loop, which consists of the upper part of the circuit, that the resistance would be larger than 2 and 200 *ohms* respectively for $A=100$ and 1000 *km* provided $\sigma_1=10^{-12}\,e.m.u.$ is assumed. Even if we take 2 *ohms*, which may be the smallest of the possible cases, the current flowing in the circuit amounts to only 6 and 1 *amperes* respectively for 1 and 24-*hour* period variations of 100 *gammas* in am-

10) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **28** (1950), 45, 219, 263, **29** (1951), 61.

plitude. If we take a higher conductivity, $\sigma_1 = 10^{-10}$ *e.m.u.* say, which seems to be possible as will be discussed in the next section, the minimum values of the resistance of the circuit would be 0.02 and 2 *ohms* respectively for $A = 100$ and 1000 *km*. Corresponding to 0.02 *ohms*, the current for 1-*hour* period variation amounts to 600 *amperes*. Since such small amounts of current produce magnetic fields of only a few *gammas* at the centre of the loop and cannot obviously account for the observed anomaly, the hypothesis of branch circuit must be abandoned unless some other means to increase the potential difference can be found.

## 4. Branch circuit and insulating wedge in the conducting mantle

Since it turns out in the last section that a simple branch circuit cannot account for the anomaly, we have to seek some other mechanism by which we may expect much larger potential difference between both the ends of the circuit. Let us consider a one-dimensional steady flow of electric current. If the conductivity of one part of the conductor is lower than that of the remaining parts, the potential drop per unit length becomes larger in the low conducting part than that in the high conducting part. In a limiting case in which the high conducting part can be regarded as a perfect conductor, the potential difference between the two ends of the low conductor becomes equal to the voltage given to the system. From the analogy of the steady flow in the above, we might be able to expect a potential difference higher than that discussed in the last section by supposing that low conducting material wedges into the conducting mantle and that the branch circuit is connected to the conducting mantle at two points just outside the wedge.

It would be extremely difficult to study electromagnetic induction in such a system of conductor. However, an approximate study, though very crude, will be made in the following. If the conducting mantle is uniform everywhere, the flow of electric current in the neighbourhood of the connecting points of the circuit is the same as that driven by the potential difference between two hypothetical plane-electrodes suitably placed in the conductor with a great distance. In the theory of electromagnetic induction within a uniform sphere, it has been well known that the induced currents flow perpendicularly to all radii and decrease gradually as the depth from the surface increases. Actually, for the conductivity considered in the last section, the current density becomes

one tenth of the surface values approximately at depths of 240 and 500 *km* respectively for 1 and 24-*hour* period variations. If we imagine that the earth's curvature can be neglected for the study of the currents around the branch circuit, the currents induced in the conductor would be approximated by the ones which are caused by the potential difference due to an imposed electromotive force given two vertical electrodes of wide contact plane, the distance between the electrodes being larger than the size of the circuit and the distribution of electric potential on the electrodes being assumed to fit the ones for the spherical case.

Even if there is an irregularity of conductivity around the connecting points of the branch circuit, the above analogy that we may take the hypothetical electrode approximation would be approximately held as long as the size of the irregularity is smaller than the wave-length of the varying magnetic field. Such a consideration would be acceptable because the induced currents are driven by electromotive forces which are excited all through the conductor and the electromotive force set up within the irregularity is to be small.

In the light of the above discussion, the influence of the insulating wedge on the distribution of electric voltage is examined by a model experiment. The experiment is conducted by use of a sheet of facsimile paper for recording by electric discharge. The paper is covered by a fine carbon film on which a very thin screen of wax is spread. If we have an electric discharge between the carbon layer and a sharp point close to the paper, a black spot is marked on the paper. Since the carbon layer is fairly uniform, the paper is a good medium for an experiment of two-dimensional steady electric current[11] though such usage of the paper is far from the original purpose.

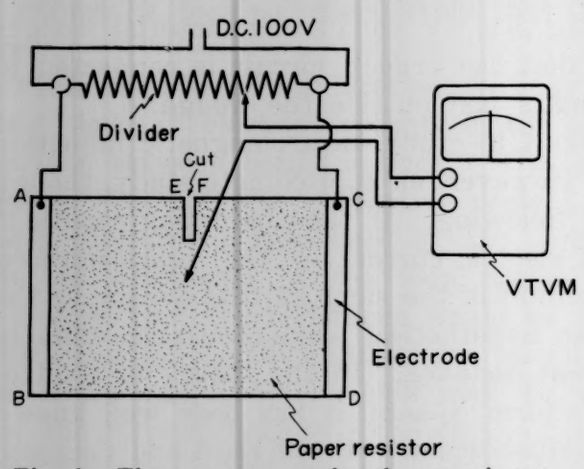

Fig. 1. The arrangement for the experiment.

We take a rectangular sheet of 35 *cm* × 25.3 *cm*. Two brass electrodes are placed on the 25 *cm* sides. The electric contact between the paper and the electrodes are made by

11) K. KASAHARA, *Bull. Earthq. Res. Inst.*, **37** (1959), 39.

putting carbon powder on the paper with a pencil. Along the central line of the paper, a cut is made as can be seen in Fig. 1. Applying 100 *volt* between $AB$ and $CD$, the potential at $E$ and $F$, the edge points of the cut, is measured by means of null method with a valve voltmeter as the detector. Since the input impedance of the meter is very high, the voltage measured is highly reliable. The voltage between $E$ and $F$ is 0.95 *volt* when there is no cut. With the increase of the depth of the cut, which is 3 *mm* in width in this case, the voltage increases as shown in Table 3 and Fig. 2.

Table 3. The voltage between $E$ and $F$ as measured by a valve-voltmeter.

| Depth (*cm*) | Voltage (*volt*) | Depth (*cm*) | Voltage (*volt*) |
|---|---|---|---|
| 0.0 | 0.95 | 13.0 | 62.5 |
| 1.0 | 7.1 | 14.0 | 66.0 |
| 2.2 | 13.9 | 15.0 | 68.0 |
| 3.0 | 18.4 | 16.0 | 72.0 |
| 4.0 | 24.2 | 17.0 | 74.0 |
| 5.0 | 29.6 | 18.0 | 75.1 |
| 6.0 | 34.8 | 19.0 | 77.5 |
| 7.0 | 38.2 | 20.0 | 79.0 |
| 8.0 | 44.0 | 21.0 | 81.0 |
| 9.0 | 48.5 | 22.0 | 82.5 |
| 10.0 | 53.5 | 23.0 | 85.0 |
| 11.0 | 57.0 | 24.0 | 86.5 |
| 12.0 | 60.0 | | |

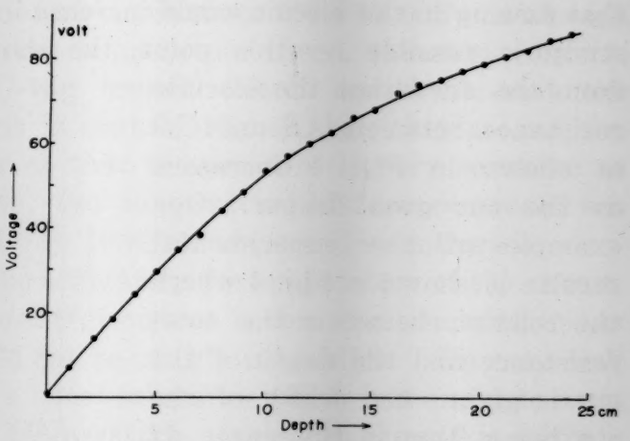


Fig. 2. The changes in the voltage between $E$ and $F$ as the depth of the cut increases.

As can be seen in the table and figure, it is noticeable that the potential difference between $E$ and $F$ increases immensely as the cut goes deeper. The ratio of the voltage to that of the case for no cut becomes 31, 56, 73 and 83 respectively for $l$ (the depth of the cut)=5, 10, 15 and 20 *cm*. In order to see the distribution of electric voltage, equipotential lines

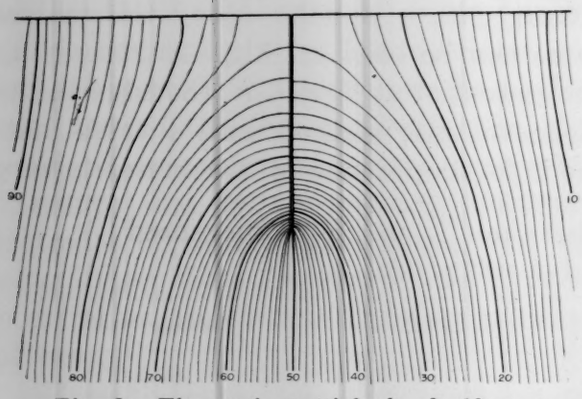


Fig. 3. The equipotentials for $l=10\,cm$.

are also measured as shown, for example, in Fig. 3 for $l=10\,cm$.

If the analogy between the above steady current model and the underground structure beneath Japan, where we suppose a wedge of low conducting material deep into the mantle as has been speculated by the writer[12], is taken for granted, it is not impossible to expect a potential difference 50 times larger than the values given in Table 2 just outside the insulating wedge. In that case, the electric current which will flow in the branch circuit connected to the outside of the wedge becomes 50 times as large as the figures obtained in the last section, amounting to 300 and 30,000 *amperes* respectively for $\sigma_1=10^{-12}$ and $10^{-10}$ *e.m.u.*, 1-*hour* period inducing field of 100 *gammas* in amplitude and $A=100\,km$ being assumed as before. There is a possibility that the current intensity would be larger than the figure cited above, because, in the case of a deep cut, the amount of electric currents flowing in the mantle would become small, while that flowing in the circuit would increase in turn. Although no accurate study is possible on this point, the above tendency may be approved from the fact that the electric resistance between *AB* and *CD* as shown in Fig. 1 increases as the cut goes deeper. One example of the experimental results is shown in Fig. 4 where the relation between the total resistance and the depth of the cut is given, the width of the cut being 3 *cm* in this case. If we take the latter value of the current intensity, the magnetic field at the centre of the loop amounts to 190 *gammas*, so that a magnetic field larger than the inducing

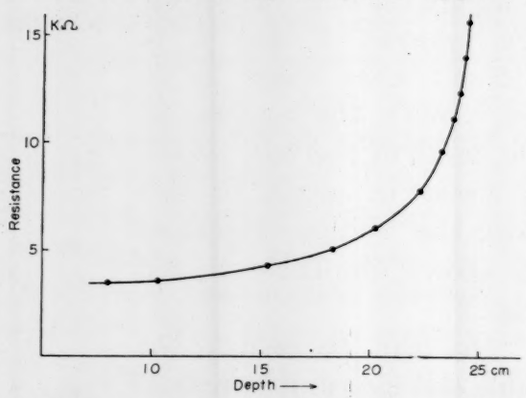


Fig. 4. The changes in the electric resistance between the electrodes as the depth of the cut increases.

12) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **34** (1956), 291.

one may be expected in this case. We therefore see that, in order to get a magnetic field equal to the inducing one, $\sigma_1=10^{-11}\sim10^{-10}$ *e.m.u.* should be taken as long as the above branch circuit model with an insulating wedge is assumed.

Now we shall examine whether or not $\sigma_1=10^{-11}\sim10^{-10}$ *e.m.u.* is possible at depths of 100∼200 *km*. Analyses of geomagnetic variations of various periods[10] suggest that the mean conductivity of the earth is as low as $10^{-15}$ *e.m.u.* at that level. We must therefore take it either that there is a special material which is different from usual composition and is of high conductivity or that the temperature is high enough in the circuit though the composition is the same.

According to experimental studies on some rocks[13),14)], it has been known that the conductivity of some rocks becomes higher than $10^{-10}$ *e.m.u.* at 1200°*C*. Although the pressure-effect is not well known, it is likely that the conductivity is reduced to less than $10^{-11}$ *e.m.u.* at depths of 100∼200 *km* as has been shown by the theory[14),15)] and experiment[16] even though the temperature is the same.

In order to make the conductivity take a value of $10^{-11}\sim10^{-10}$ *e.m.u.* at the 100∼200 *km* depth, therefore, we are obliged to assume a temperature higher than 1200°*C* in the circuit as long as the composition of the material is something not greatly different from peridotite, gabbro or basalt. The temperature at that depth obtained by T. Rikitake[15] for the averaged state of the earth amounts to 900∼1100°*C*. Although some others gave slightly higher temperature there, the most conceivable way of interpretation of the branch circuit would be that the temperature inside the circuit is slightly higher than that around the circuit. Since the conductivity at that temperature is very sensitive to slight changes in temperature, the temperature difference would not be large, probably less than a few hundred *degrees* in centigrade.

It is not possible to determine accurately the temperature of the circuit. The essential point of the present discussion is that the conductivity as high as $10^{-11}\sim10^{-10}$ *e.m.u.* would not be utterly impossible. We may well expect such a conductivity for a usual substance which is thought to exist at that depth provided the temperature within the circuit is slightly higher than that in its environment. However, nothing is known about the reason why there exists such a high temperature circuit.

13) T. NAGATA, *Bull. Earthq. Res. Inst.*, **15** (1937), 663.
14) H. P. COSTER, *M. N. R. A. S. Geophys. Suppl.*, **5** (1949), 193.
15) T. RIKITAKE, *Bull. Earthq. Res. Inst.*, **30** (1952), 13.
16) H. HUGHES, *Journ. Geophys. Res.*, **60** (1955), 187.

## 5. Electromagnetic induction in a spherical conducting sheet with a hole

As the writer has often pointed out, the anomalous behaviour of geomagnetic variations in Japan seems unlikely to be ascribed to the effect of the magnetic field produced by the electric currents induced in the sea surrounding Japan. Since the question whether the anomaly might be caused by the influence of the sea is still sometimes raised by some geophysicists, however, the writer would here like to add one more study on the nature of such an effect upon the previous discussion.

Let us take a spherical conducting sheet with a circular hole. By the model, it would be possible to study approximately the effect of the sea which surrounds a non-conducting land mass. The non-conducting land occupies the inside area of the circular spherical sheet defined by $\theta=\theta_0$, the $\theta=0$ axis crosses the spherical surface at the centre of the area. The inducing magnetic field may take any type. For the sake of mathematical simplicity, however, it is first assumed that the field is uniform and parallel (*Case 1*) or perpendicular (*Case 2*) to the $\theta=0$ axis.

*Case 1.*

The arrangement of the model for this case is shown in Fig. 5.

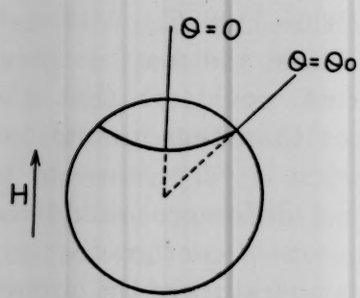

Fig. 5. *Case 1.*

Following the procedure developed in the 6th report[2], the magnetic potential of the inducing field is expressed as

$$W_e=-rHP_1(\cos\theta)\,. \qquad (12)$$

The current function of the induced electric currents can be expressed as

$$\Psi=\sum_n a_n P_n(\cos\theta)\,, \qquad (13)$$

the expression being effective not only on the conducting part of the sheet but on the whole surface of the sphere of which the radius is denoted by $a$.

The boundary condition at $r=a$ becomes

$$\Psi=0 \quad \text{on} \quad 0<\theta<\theta_0\,, \qquad (14)$$

$$\frac{1}{a^2}\left\{\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)\right\}\Psi=K\frac{\partial H_r}{\partial t} \quad \text{on} \quad \theta_0<\theta<\pi\,, \qquad (15)$$

in which $K$ and $H_r$ denote respectively the integrated conductivity and the radial component of the magnetic field. The magnetic permeability is assumed as unity in electromagnetic unit.

For a sudden change, (15) becomes

$$H_r=0\ . \tag{16}$$

Even for a periodic inducing field, this will be a good approximation of (15) in so far as the induction in a sheet of the earth's size by changes having periods of a few *minutes* is concerned.

(16) can be written as

$$\frac{aH_0}{4\pi}P_1+\sum_n\frac{n(n+1)}{2n+1}a_nP_n=0\ , \tag{17}$$

where $H_0$ is the amplitude of the uniform magnetic field suddenly applied from outside. From (14) and (17), the boundary condition at $r=a$ can be expressed as

$$\left.\begin{aligned}&\sum_n a_nP_n=0 \quad \text{for} \quad 0<\theta<\theta_0\ ,\\ &\sum_n a_nP_n=-\sum_n\left\{\frac{n(n+1)}{2n+1}-1\right\}a_nP_n-\frac{aH_0}{4\pi}P_1\ , \quad \text{for} \quad \theta_0<\theta<\pi\ .\end{aligned}\right\} \tag{18}$$

After multiplying by $P_N\sin\theta$, we shall integrate (18) with respect to $\theta$ from $\theta=0$ to $\pi$. In that case, the integral should be divided into two parts, the first being from $\theta=0$ to $\theta=\theta_0$ and the second from $\theta=\theta_0$ to $\theta=\pi$.

We thus obtain

$$\begin{aligned}&a_NK_{NN}+\sum_n\left\{\frac{n(n+1)}{2n+1}-1\right\}a_n\left(K_{nN}-\int_0^{\theta_0}P_nP_N\sin\theta d\theta\right)\\ &=-\frac{aH_0}{4\pi}\left(K_{1N}-\int_0^{\theta_0}P_1P_N\sin\theta d\theta\right)\ ,\end{aligned} \tag{19}$$

where

$$K_{nN}=\int_0^{\pi}P_nP_N\sin\theta d\theta\ . \tag{20}$$

It is readily seen that

$$\int_0^{\theta_0}P_nP_N\sin\theta d\theta=\frac{\sin\theta_0\left(\dfrac{dP_N}{d\theta}P_n-\dfrac{dP_n}{d\theta}P_N\right)_{\theta=\theta_0}}{(n-N)(n+N+1)} \quad \text{for} \quad n\neq N\ , \tag{21}$$

Table 4. $K_{nN}-\int_0^{\theta_0} P_n P_N \sin\theta\, d\theta$ ($\theta_0=20°$).

| $n$ | $N$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 0.60992 | −0.05336 | −0.04853 | −0.04255 | −0.03576 | −0.02853 | −0.02126 | −0.01448 | −0.00802 | −0.00264 | 0.00165 | 0.00475 |
| 2 | −0.05336 | 0.34975 | −0.04581 | −0.04030 | −0.03404 | −0.02737 | −0.02064 | −0.01434 | −0.00833 | −0.00328 | 0.00077 | 0.00375 |
| 3 | −0.04853 | −0.04581 | 0.24380 | −0.03708 | −0.03157 | −0.02568 | −0.01972 | −0.01412 | −0.00874 | −0.00417 | −0.00046 | 0.00233 |
| 4 | −0.04255 | −0.04030 | −0.03708 | 0.18915 | −0.02848 | −0.02356 | −0.01855 | −0.01380 | −0.00919 | −0.00524 | −0.00194 | 0.00061 |
| 5 | −0.03576 | −0.03404 | −0.03157 | −0.02848 | 0.15689 | −0.02110 | −0.01716 | −0.01336 | −0.00964 | −0.00638 | −0.00357 | −0.00131 |
| 6 | −0.02853 | −0.02737 | −0.02568 | −0.02356 | −0.02110 | 0.13545 | −0.01558 | −0.01278 | −0.01002 | −0.00749 | −0.00522 | −0.00327 |
| 7 | −0.02126 | −0.02064 | −0.01972 | −0.01855 | −0.01716 | −0.01558 | 0.11968 | −0.01201 | −0.01027 | −0.00848 | −0.00675 | −0.00515 |
| 8 | −0.01448 | −0.01434 | −0.01412 | −0.01380 | −0.01336 | −0.01278 | −0.01201 | 0.10676 | −0.01056 | −0.00937 | −0.00815 | −0.00686 |
| 9 | −0.00802 | −0.00833 | −0 00874 | −0.00919 | −0.00964 | −0.01002 | −0.01027 | −0.01056 | 0.09545 | −0.00974 | −0.00907 | −0.00817 |
| 10 | −0.00264 | −0.00328 | −0.00417 | −0.00524 | −0.00638 | −0.00749 | −0.00848 | −0.00937 | −0.00974 | 0.085600 | −0.00968 | −0.00912 |
| 11 | 0.00165 | 0.00077 | −0.00046 | −0.00194 | −0.00357 | −0.00522 | −0.00675 | −0.00815 | −0.00907 | −0.00968 | 0.073746 | −0.00963 |
| 12 | 0.00475 | 0.00375 | 0.00233 | −0.00061 | −0.00131 | −0.00327 | −0.00515 | −0.00686 | −0.00817 | −0.00912 | −0.00963 | 0.070582 |

Table 5. The coefficients and the righthand members of the simultaneous equations (19).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | righthand member* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | −0.02270 | −0.07537 | −0.11471 | −0.13641 | −0.13956 | −0.12620 | −0.10118 | −0.06488 | −0.02442 | 0.01807 | 0.05533 | 1.31627 |
| 0.03839 | 1 | −0.07115 | −0.10865 | −0.12986 | −0.13390 | −0.12253 | −0.10018 | −0.06739 | −0.03033 | 0.00843 | 0.04368 | −0.11354 |
| 0.03492 | −0.01949 | 1 | −0.09996 | −0.12043 | −0.12563 | −0.11706 | −0.09865 | −0.07070 | −0.03856 | −0.00504 | 0.02714 | −0.10553 |
| 0.03060 | −0.01715 | −0.05761 | 1 | −0.10863 | −0.11526 | −0.11011 | −0.09643 | −0.07434 | −0.04846 | −0.02123 | 0.00711 | −0.09385 |
| 0.02572 | −0.01449 | −0.04904 | −0.07678 | 1 | −0.10322 | −0.10186 | −0.09334 | −0.07798 | −0.05900 | −0.03909 | −0.01525 | −0.07897 |
| 0.02052 | −0.01221 | −0.03988 | −0.06352 | −0.08050 | 1 | −0.09250 | −0.08930 | −0.08105 | −0.06926 | −0.05716 | −0.03808 | −0.06256 |
| 0.01530 | −0.00879 | −0.03064 | −0.05000 | −0.06546 | −0.07623 | 1 | −0.08392 | −0.08308 | −0.07842 | −0.07391 | −0.06000 | −0.04617 |
| 0.01042 | −0.00611 | −0.02194 | −0.03721 | −0.05097 | −0.06252 | −0.07130 | 1 | −0.08542 | −0.08665 | −0.08922 | −0.07992 | −0.03127 |
| 0.00576 | −0.00355 | −0.01357 | −0.02477 | −0.03677 | −0.04901 | −0.06096 | −0.07377 | 1 | −0.09008 | −0.09930 | −0.09517 | −0.01736 |
| 0.00190 | −0.00138 | −0.00648 | −0.01412 | −0.02434 | −0.03664 | −0.05034 | −0.06546 | −0.07880 | 1 | −0.10597 | −0.10624 | −0.00576 |
| −0.00119 | 0.00032 | −0.00072 | −0.00523 | −0.01363 | −0.02553 | −0.04007 | −0.05695 | −0.07336 | −0.08951 | 1 | −0.11217 | 0.00381 |
| −0.00341 | 0.00160 | 0.00361 | 0.00165 | −0.00499 | −0.01599 | −0.03058 | −0.04792 | −0.06609 | −0.08434 | −0.10544 | 1 | 0.01056 |

* The righthand members should be multiplied by $-(aH_0/4\pi)$.

and

$$(2N+3)\int_0^{\theta_0}(P_{N+1})^2\sin\theta\,d\theta$$
$$=(2N+1)\int_0^{\theta_0}(P_N)^2\sin\theta d\theta-\cos\theta_0\{(P_{N+1})^2+(P_N)^2\}_{\theta=\theta_0}+2(P_NP_{N+1})_{\theta=\theta_0}$$
$$\text{for } n=N. \qquad (22)$$

With the aid of (21) and (22), $K_{nN}-\int_0^{\theta_0}P_nP_N\sin\theta d\theta$ can be calculated as given in Table 4 for $\theta_0=20°$. With these values, (19) can be regarded as the simultaneous equations for $a_1, a_2, \cdots, a_{12}$. The coefficients of $a_n$'s and the righthand members are given in Table 5. Since the coefficients of the diagonal terms are relatively large, we can easily solve the equations though no account is taken of the rigorous proof concerning the convergency. The solutions that are solved by making use of the relaxation method are given in Table 6.

Table 6. The solutions of (19) in units of $-aH_0/4\pi$.

| $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ |
|---|---|---|---|---|---|
| 1.186 | −0.279 | −0.250 | −0.221 | −0.191 | −0.161 |
| $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ |
| −0.131 | −0.101 | −0.072 | −0.046 | −0.024 | −0.007 |

Since we have obtained $a_n$'s, the current function can be calculated from (13) as shown in Fig. 6. In the figure, the current function that should have been obtained if the sheet has no hole is also shown. We see that the condition that the current function should be zero for $0<\theta<20°$ is not exactly satisfied. The fact is due to the procedure of calculation in which we only take harmonics for $n=1, 2, \cdots, 12$. In order to conduct a more accurate

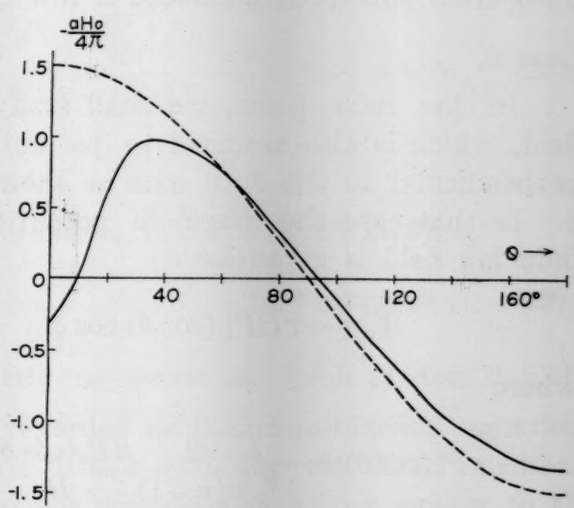


Fig. 6. The distribution of the current function for *Case 1* (full line) and that for a sheet without hole (broken line).

study, some more harmonics should be taken into account though such an analysis would be tedious. The writer is of the opinion, however, that the general tendency of the effect of the hole could be investigated by the present study.

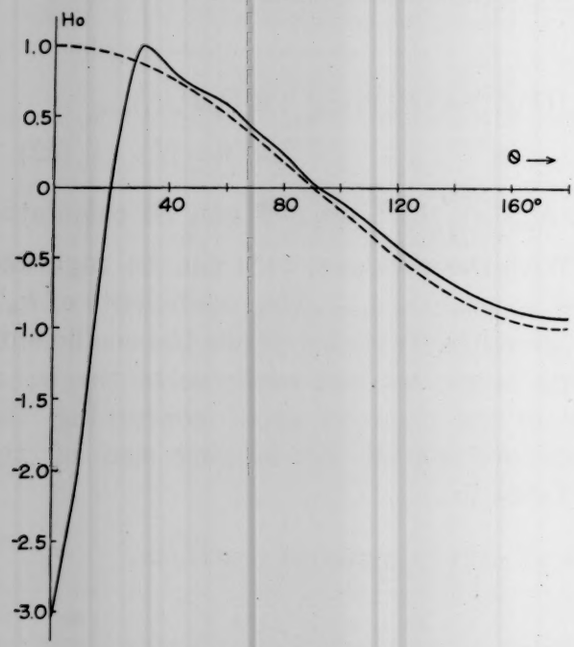


Fig. 7. The distribution of the normal component of the induced magnetic field for *Case 1* (full line) and that for a sheet without hole (broken line).

The normal component of the magnetic field produced by the induced electric currents are also easily calculated with the coefficients given in Table 6 as can be seen in Fig. 7 in which the reversed external field or the induced field for the sheet with no hole is also shown. It is clearly seen that the induced field nearly cancels the inducing one on the conducting sheet. On the other hand, the direction of the induced field is the same as that of the inducing one over the non-conducting hole, so that the magnetic field suddenly applied from outside is enhanced a few times near the centre of the hole.

*Case 2.*

In the next place, we shall study the case in which the external field, which is also assumed to be uniform, is applied to a direction perpendicular to the $\theta=0$ axis as shown in Fig. 8. In that case the magnetic potential of the inducing field is given as

$$W_e=-rHP_1^1(\cos\theta)\cos\phi\ . \qquad (23)$$

where

$$P_n^1(\cos\theta)=-\sqrt{\frac{2}{n(n+1)}}\frac{dP_n(\cos\theta)}{d\theta}\ .$$

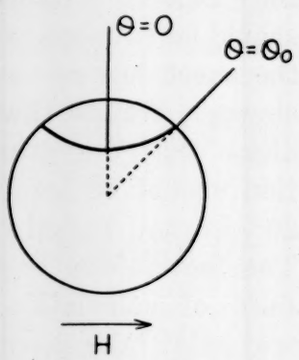


Fig. 8. *Case 2*

The current function of the induced field is to be of the form such as

$$\Psi=\sum_n b_n P_n^1 \cos\phi \ . \tag{24}$$

From the boundary condition that the current function is zero on $0<\theta<\theta_0$ and that the normal component of magnetic field vanishes on $\theta_0<\theta<\pi$ as we have dealt with before, we obtain

$$\left.\begin{aligned} &\sum_n b_n P_n^1=0 && \text{for} \quad 0<\theta<\theta_0 \ , \\ &\sum_n b_n P_n^1=-\sum_n\left\{\frac{n(n+1)}{2n+1}-1\right\}b_n P_n^1-\frac{aH_0}{4\pi}P_1^1 && \text{for} \quad \theta_0<\theta<\pi \ . \end{aligned}\right\} \tag{25}$$

After multiplying by $P_n^1 \sin\theta$, we shall integrate (25) with respect to $\theta$ from $\theta=0$ to $\theta=\pi$ in a fashion similar to the former case. We then have

$$\begin{aligned} &b_N M_{NN}+\sum_n\left\{\frac{n(n+1)}{2n+1}-1\right\}b_n\left(M_{nN}-\int_0^{\theta_0}P_n^1 P_N^1 \sin\theta d\theta\right) \\ &\quad=-\frac{aH_0}{4\pi}\left(M_{1N}-\int_0^{\theta_0}P_1^1 P_N^1 \sin\theta d\theta\right), \end{aligned} \tag{26}$$

where

$$M_{nN}=\int_0^{\pi}P_n^1 P_N^1 \sin\theta d\theta \ . \tag{27}$$

Since we have the relations such as

$$\int_0^{\theta_0}P_n^1 P_N^1 \sin\theta d\theta=\frac{\sin\theta_0\left(\dfrac{dP_N^1}{d\theta}P_n^1-\dfrac{dP_n^1}{d\theta}P_N^1\right)_{\theta=\theta_0}}{(n-N)(n+N+1)} \quad \text{for} \quad n\neq N \ , \tag{28}$$

and

$$\int_0^{\theta_0}(P_N^1)^2 \sin\theta d\theta=2\int_0^{\theta_0}(P_N)^2 \sin\theta d\theta-\sqrt{\frac{2(N-1)!}{(N+1)!}}(P_N P_N^1 \sin\theta)_{\theta=\theta_0}$$
$$\text{for} \quad n=N, \tag{29}$$

we can obtain $M_{nN}-\int_0^{\theta_0}P_n^1 P_N^1 \sin\theta d\theta$ as given in Table 7 for $\theta_0=20°$. With these values, (26) can be regarded as the simultaneous equations for $b_1, b_2, \cdots, b_{12}$. The coefficients of $b_n$'s and the righthand members are given in Table 8. Solving the equations in a way similar to the previous case, we can determine $b_n$'s as given in Table 9.

The current function and the normal component of the induced field

Table 7. $M_{nN} - \int_0^{\theta_0} P_n^1 P_N^1 \sin\theta \, d\theta$ ($\theta_0 = 20°$).

| $n$ | $N$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 1.32976 | −0.00593 | −0.00787 | −0.00934 | −0.01027 | −0.01062 | −0.01027 | −0.00992 | −0.00863 | −0.00704 | −0.00535 | −0.00360 |
| 2 | −0.00593 | 0.79014 | −0.01310 | −0.01555 | −0.01710 | −0.01770 | −0.01713 | −0.01658 | −0.01446 | −0.01184 | −0.00905 | −0.00614 |
| 3 | −0.00787 | −0.01310 | 0.55400 | −0.02070 | −0.02278 | −0.02362 | −0.02288 | −0.02224 | −0.01945 | −0.01599 | −0.01232 | −0.00848 |
| 4 | −0.00934 | −0.01555 | −0.02070 | 0.41983 | −0.02713 | −0.02818 | −0.02730 | −0.02672 | −0.02348 | −0.01942 | −0.01513 | −0.01061 |
| 5 | −0.01027 | −0.01710 | −0.02278 | −0.02713 | 0.33368 | −0.03121 | −0.03019 | −0.02989 | −0.02639 | −0.02202 | −0.01738 | −0.01248 |
| 6 | −0.01062 | −0.01770 | −0.02362 | −0.02818 | −0.03121 | 0.27509 | −0.03122 | −0.03169 | −0.02814 | −0.02370 | −0.01904 | −0.01406 |
| 7 | −0.01027 | −0.01713 | −0.02288 | −0.02730 | −0.03019 | −0.03122 | 0.23474 | −0.03298 | −0.02890 | −0.02450 | −0.02002 | −0.01523 |
| 8 | −0.00992 | −0.01658 | −0.02224 | −0.02672 | −0.02989 | −0.03169 | −0.03298 | 0.20888 | −0.02817 | −0.02452 | −0.02069 | −0.01642 |
| 9 | −0.00863 | −0.01446 | −0.01945 | −0.02348 | −0.02639 | −0.02814 | −0.02890 | −0.02817 | 0.18537 | −0.02319 | −0.02024 | −0.01674 |
| 10 | −0.00704 | −0.01184 | −0.01599 | −0.01942 | −0.02202 | −0.02370 | −0.02450 | −0.02452 | −0.02319 | 0.16947 | −0.01936 | −0.01669 |
| 11 | −0.00535 | −0.00905 | −0.01232 | −0.01513 | −0.01738 | −0.01904 | −0.02002 | −0.02069 | −0.02024 | −0.01936 | 0.15642 | −0.01635 |
| 12 | −0.00360 | −0.00614 | −0.00848 | −0.01061 | −0.01248 | −0.01406 | −0.01523 | −0.01642 | −0.01674 | −0.01669 | −0.01635 | 0.14489 |

Table 8. The coefficients and the righthand members of the simultaneous equations (26).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | righthand member* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | −0.00124 | −0.00581 | −0.01193 | −0.01887 | −0.02571 | −0.03090 | −0.03522 | −0.03571 | −0.03284 | −0.02770 | −0.02052 | 1.49397 |
| −0.00222 | 1 | −0.00968 | −0.01985 | −0.03143 | −0.04285 | −0.05155 | −0.05888 | −0.05982 | −0.05522 | −0.04686 | −0.03500 | −0.00619 |
| −0.00294 | −0.00273 | 1 | −0.02642 | −0.04186 | −0.05719 | −0.06885 | −0.07897 | −0.08047 | −0.07458 | −0.06380 | −0.04835 | −0.00814 |
| −0.00349 | −0.00325 | −0.01529 | 1 | −0.04985 | −0.06823 | −0.08215 | −0.09489 | −0.09714 | −0.09057 | −0.07834 | −0.06049 | −0.00975 |
| −0.00384 | −0.00357 | −0.01682 | −0.03463 | 1 | −0.07556 | −0.09085 | −0.10614 | −0.10919 | −0.10269 | −0.09000 | −0.07115 | −0.01093 |
| −0.00398 | −0.00370 | −0.01744 | −0.03597 | −0.05735 | 1 | −0.09395 | −0.11254 | −0.11642 | −0.11053 | −0.09859 | −0.08014 | −0.01153 |
| −0.00384 | −0.00358 | −0.01690 | −0.03485 | −0.05548 | −0.07558 | 1 | −0.11711 | −0.11956 | −0.11426 | −0.10367 | −0.08682 | −0.01131 |
| −0.00372 | −0.00347 | −0.01643 | −0.03411 | −0.05493 | −0.07672 | −0.09925 | 1 | −0.11655 | −0.11436 | −0.10713 | −0.09360 | −0.01089 |
| −0.00324 | −0.00302 | −0.01436 | −0.02997 | −0.04849 | −0.06813 | −0.08697 | −0.10004 | 1 | −0.10815 | −0.10481 | −0.09543 | −0.00955 |
| −0.00264 | −0.00247 | −0.01181 | −0.02479 | −0.04046 | −0.05738 | −0.07373 | −0.08707 | −0.09594 | 1 | −0.10025 | −0.09515 | −0.00775 |
| −0.00200 | −0.00189 | −0.00910 | −0.01931 | −0.03194 | −0.04610 | −0.06025 | −0.07347 | −0.08373 | −0.09029 | 1 | −0.09320 | −0.00585 |
| −0.00135 | −0.00128 | −0.00627 | −0.01354 | −0.02294 | −0.03404 | −0.04583 | −0.05830 | −0.06925 | −0.07784 | −0.08466 | 1 | −0.00392 |

* The righthand members should be multiplied by $-(aH_0/4\pi)$.

Table 9. The solutions of (26) in units of $-aH_0/4\pi$.

| $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ |
|---|---|---|---|---|---|
| 1.491 | −0.008 | −0.010 | −0.012 | −0.013 | −0.014 |
| $b_7$ | $b_8$ | $b_9$ | $b_{10}$ | $b_{11}$ | $b_{12}$ |
| −0.014 | −0.013 | −0.012 | −0.010 | −0.009 | −0.007 |

on $\phi=0$ are calculated with $b_n$'s in Table 9 as can be seen in Figs. 9 and 10 where the curves for a sheet without hole are also illustrated. Although the approximation with the twelve harmonics does not seem to be satisfactory as we have seen in the previous case, we see that the differences between the curves

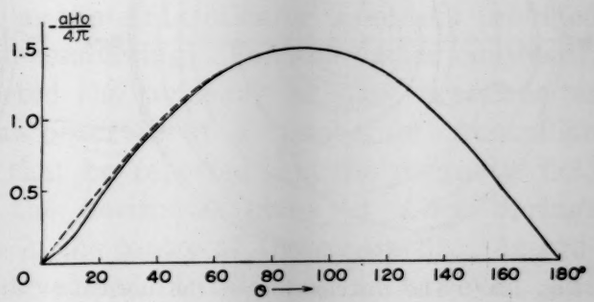


Fig. 9. The distribution of the current function on $\phi=0$ for *Case 2* (full line) and that for a sheet without hole (broken line).

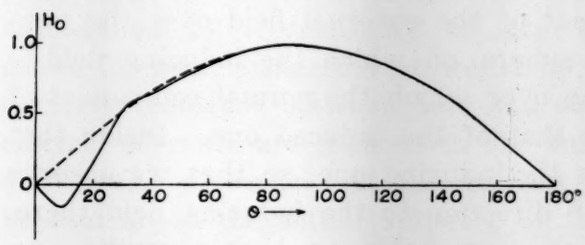


Fig. 10. The distribution of the normal component of the induced magnetic field on $\phi=0$ for *Case 2* (full line) and that for a sheet without hole (broken line).

as well as the induced magnetic field can be obtained for a uniform inducing field of any direction. Suppose the inducing field has an inclination $\alpha$ to the $\theta=0$ axis as shown in Fig. 11, the current function becomes

$$\Psi=\cos\alpha\sum_n a_nP_n(\cos\theta)+\sin\alpha\sum_n b_nP_n^1(\cos\theta)\cos\phi\ . \qquad (30)$$

for the sheet with and without the hole are not as large as those in *Case 1*. The influence of the non-conducting hole can be seen only in the neighbourhood of the hole.

*Case 3.*

If we combine the results for *Case 1* with those for *Case 2*, the current function

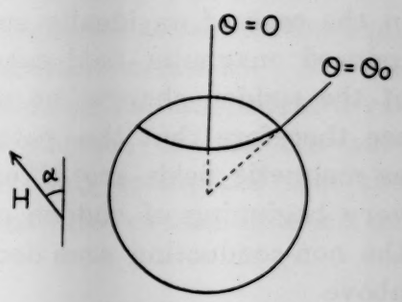


Fig. 11. *Case 3.*

The distribution of the normal component of the induced magnetic field over the spherical surface is shown in Fig. 12 for $\alpha=45°$. Even

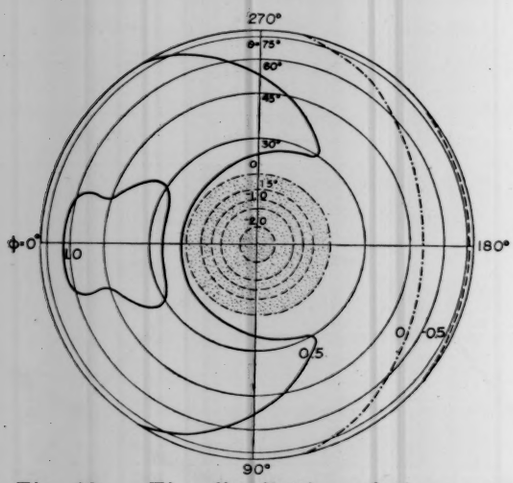


Fig. 12a. The distribution of the normal component of the induced magnetic field for *Case 3* ($\alpha=45°$) viewed from a point right above the hole. The hole is shown by the shadow area.

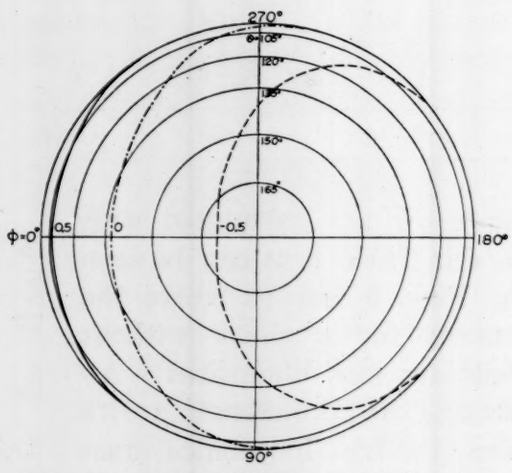


Fig. 12b. The distribution of the same component over another hemi-sphere.

in this case, we see an enhancement of the external field over the non-conducting area. On the hemi-sphere on which the inducing field is directed outwards, there is a zone over which the normal component of the inducing field is cancelled by that of the induced one. Inside that zone, the induced field overcomes the inducing one, so that we observe a normal component in opposite direction to the inducing field there. But the resultant field is not as remarkable as that over the non-conducting area.

The above study has been made on the assumption that the area between $\theta=0$ to $\theta=\theta_0$ is absolutely non-conducting. In an actual case, however, the conductivity over that area must be finite. It is known that, in the case of an ideally sudden change, the normal component of the induced magnetic field cancels that of the inducing one at the instant of the sudden change, no matter how small the conductivity is. We see therefore that the pattern of the induced electric currents as well as magnetic fields are different from the ones obtained above at the very beginning of sudden changes. However, the induced currents in the non-conducting area decay very quickly reaching the state discussed above.

The currents induced in the conducting area decay more slowly.

Since it is tedious to study such a decay quantitatively, no account is taken of it here. But as can be supposed from what we have discussed in the 6th report[2], it is unlikely that the general tendency of the distribution of the induced currents and fields for a sudden change would be seriously modified so long as we consider a uniform inducing field together with a sea having a depth of hundreds or thousands of *meters*.

The model treated in the above seems to fit well for studying the influence of the land masses such as the Antarctica or Australia provided the continent is regarded as non-conducting. For the latter continent, W.D. Parkinson[17] recently reported the tendency of the directions of rapid geomagnetic fluctuations as observed at a number of Australian observatories. It is interesting that he reported that the magnetic field vectors are almost confined in the horizontal plane at Alice Springs which is situated approximately in the centre of the continent. According to the mathematical study developed in this paper, however, the vertical magnetic field should be large at the centre of the non-conducting land mass.

The disagreement between the theory and the observational result may suggest that the continent cannot be treated as an ideal insulator surrounded by a conductor of large extent. The possible way to account for such disagreement would be to assume either that the conductivity contrast between land and sea is not so large or that no strong electric currents are induced in the surrounding owing to the irregular distribution of lands. At the moment, therefore, nothing definite can be said about the actual influence of the sea on geomagnetic variations of short period.

It is more difficult to investigate the effect of the sea surrounding Japan because the shape of the land is greatly different from that of the model considered. It may be said, however, that we should observe upward magnetic fields in Japan on occasions of sudden commencement of magnetic storm provided the land area is regarded as non-conducting. This is not the case for the Japanese geomagnetic variations. We observe, on the contrary, downward magnetic fields in the anomalous area. Although it is not possible to examine the influence of the sea surrounding Japan quite accurately, it is hardly likely to suppose that the anomalous features of short-period variations are caused by such an influence.

17) W. D. PARKINSON, *Geophys. Journ. Roy. Astro. Soc.*, **2** (1959), 1.

In the light of the above discussion together with that was studied in the 6th report[2], the anomaly of geomagnetic variations found in Japan is not of the type which might be caused by the electric currents induced in the sea. One might further raise a question, however, that the anomalous underground structure, which has been suggested in the last section, would be responsible for the anomaly. The non-conducting wedge penetrating into the conducting mantle as supposed in the last section gives a configuration somewhat alike the model considered in this section. It seems also unlikely that such a particular structure can give rise to the anomaly in Japan.

## 6. Concluding remarks

The possible cause of the anomaly of short-period geomagnetic variations as observed in Japan is discussed as closely as possible in this paper. Since it turns out that an isolated conductor model embedded in the upper part of the earth's mantle as well as a simple branch circuit model which is connected to the conducting part of the mantle cannot account for the anomaly, the only possible way to give rise to such an anomaly seems to be effected by assuming a branch circuit together with a non-conducting wedge penetrating into the mantle. Large parts of the electric currents induced in the mantle by geomagnetic variations can flow in the circuit both the ends of which are connected to the outside of the wedge. In this case, it is not impossible to observe a large amplitude of vertical component as found by actual observations provided the circuit takes a suitable form underneath Japan.

The penetrating wedge supposed harmonizes well with the low conductivity as has been suggested from the analyses of *Sq* and *Dst* in Japan.

The underground structure thus presumed is an extraordinarily complicated one. Although the writer[12] speculated its significance in relation to the occurrence of deep focus earthquakes, orogenic activity and so forth, nothing definite has been known about the nature of the branch circuit or wedge-shape penetration supposed here. Since it seems likely that the underground conditions brought out by geomagnetic method has an important bearing on geophysical and geological phenomena in Japan, it is highly desirable to conduct some further observations together with some more elaborate analyses.

From the investigation on the electromagnetic induction within a spherical sheet having a non-conducting hole, it is concluded that the

anomaly is not of the type which might be caused by the influence of the sea surrounding Japan. But it seems important that no large vertical fluctuations of geomagnetic field are actually observed in the central area of Australia which seems to fit well the model treated, while the theory suggests that the vertical component should be large there. One of the ways of compromise would be to suppose that the conductivity contrast between land and sea is not so large as that considered in the model from some unknown reason. Although this topic is not directly related to the anomaly of geomagnetic variations in Japan, much attention should be paid to a better understanding of the influence of sea on geomagnetic variations in the future.

In conclusion, the writer thanks to Messers K. Kasahara and I. Tanaoka for their help in the experiment. He also wishes to express his sincere thanks to Miss E. Nakagawa for her assistance in the numerical work. The writer would like to extend his thanks to the Ministry of Education who provided financial aid for this study through a Research Grant.

# 35. 日本における地磁気短周期変化の異常と地下構造 (第 9 報)

地震研究所 力武常次

日本中部において，地磁気変化がきわめていちじるしい異常を示すことは，第 8 報までの各報告に詳しく述べたところである．

本報においては，その異常の原因として推測されてきた地下の特殊構造に対し，できる限りの量的吟味を加えることを目的とする．

まず第一に，地下に導体が独立して存在する場合，地磁気変化によつて導体中に誘起される電流のつくる磁場の影響を調べた．球状導体を仮定する場合には，半径 400 *km*，電気伝導度 $10^{-12}$ *e.m.u.* 以上ということになり，このように巨大な異常領域の存在は考えにくいし，当然 *Sq* および *Dst* のようなおそい変化に対してもその影響が顕著にあらわれることになり，観測事実と相反する．つぎに，輪状導体の存在を仮定する場合にも，可能と考えられる大きさおよび電気的性質に対し，周期 1 時間程度の外部磁場変化に際して，その 1/50 以上の誘導磁場を期待することは困難である．

したがつて，独立導体モデルが無理であるからには，日本の地磁気変化異常を発生する電流は地球中間層の深さ 400 *km* より下の部分 (この部分は導電的であることが知られている) より上昇している回路に沿つて流れるものと考えてみよう．異常地域のひろがりから，分岐回路が導電領域に連結する 2 点間の距離を 1000 *km* 程度と推定する．地磁気変化の際にこの 2 点間に生じる電位差をみつもり，回路の抵抗を計算してみると，非常に好都合の場合を採用しても，周期 1 時間，振幅 100 ガンマの変化に対し 600 アンペア程度の電流が期待されることになるが，これは異常磁場の数パーセントを説明するにすぎない．したがつて，上記 2 点間の電位差を増加させることが可能とならない限り，分岐回路モデルによる説明は困難である．

*Sq* および *Dst* の解析より，日本地下数 100 *km* の電気伝導度が地球全体の平均にくらべて小さいことが示唆されているので，上述モデルの 2 点間に高抵抗のくさび状領域を仮想する．この場合には，2 点間の電位差はいちじるしく増加し，くさびのない場合の 50 倍の電位差を得ることも無理でないことが，カーボン記録紙を使用した模型実験により察知される．このようにして推定された日本地下の特殊構造がユニークであるという保証はないが，現在の段階においては，各種地磁気変化の異常をほぼ統一的に説明できるモデルであるということができよう．

なお本報においては，海中に誘導される電流の影響に関し，新しい研究をつけ加えた．陸を非電導性と考え，導電球殻の一部に円孔がある場合の一様磁場による電磁誘導を調べた．その結果，円孔つまり陸の中心部では外部磁場と同方向に磁場が発生することがわかつた．したがつて，日本において観測される異常磁場は全く反対の符号を有することとなり，日本をとりまく海洋の影響と考えてこの異常磁場を説明することはできない．

最近の報告によれば，オーストラリア大陸中心部の地磁気観測所において，鉛直分力変化がほとんどないことが報告されている．ここに取扱つたモデルは同大陸によく適合するものと考えられるにもかかわらず，理論と実測との間にいちじるしい相違があるということは，陸と海との電気伝導度のコントラストについて，従来のような簡単な考え方が成立たないことを示しているのかもしれない．

BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 37 (1959), pp. 571-592

# 36. *Studies of the Thermal State of the Earth. The Third Paper: Terrestrial Heat Flow at Hitachi, Ibaraki Prefecture, Japan.**

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(Read July 22 and Sept. 22, 1959.—Received Sept. 30, 1959.)

**Summary**

From 68 measurements of rock temperature made at various points in drifts of Hitachi copper mine, geothermal gradients at these places were determined. The thermal gradient was found to be $0.94\times10^{-2}$ °*C/m* and $1.21\times10^{-2}$ °*C/m* in the north and the south parts of the mine respectively. Thermal conductivity of 36 rock specimens collected from various parts of the mine was measured using the divided-bar method. Apparent thermal conductivities of the rocks at the two parts are $6.73\sim7.08\times10^{-3}$ *cal/cm sec* °*C* and $6.50\sim7.43\times10^{-3}$ *cal/cm sec* °*C*. The terrestrial heat flow from the interior to the surface of the earth was computed to be $0.63\sim0.67\times10^{-6}$ cal/*cm*$^2$ *sec* for the north part and $0.78\sim0.90\times10^{-6}$ *cal/cm*$^2$ *sec* for the south part. These values are a little smaller than those already found in Japan.

## 1. Introduction

Determinations of the terrestrial heat flow have recently been made at several places in Japan by the Earthquake Research Institute. Preliminary heat flow values have already been published in this bulletin[1]. The results which were obtained by the writer in the Hitachi mine and are described in this paper will form an additional datum for studying thermal conditions in Japan. In the present study, so many observations of underground temperature and measurements of thermal conductivity of rock samples are made, that the heat flow value computed therefrom will be fairly reliable. The study was made possible by the permission and help given by the Nihon Kogyo Co. which operates the Hitachi mine (Ibaraki Prefecture). The location and topographical and structural

* Communicated by T. Rikitake.

1) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **36** (1958), 251.

Fig. 1. Map of Japan indicating the locality of Hitachi. Other localities where thermal investigation has been carried out are also shown.

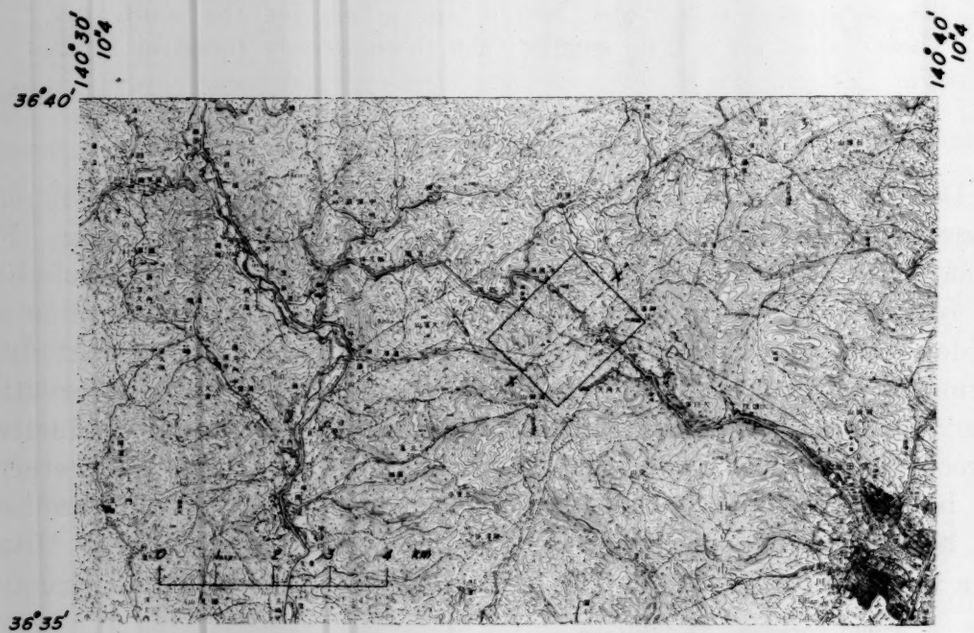



Fig. 2. Topographic map of Hitachi. Framed area was under investigation.

features of the mine are shown in Figs. 1～3. Rock temperature was measured at 68 points in the drifts as shown in Fig. 4 i)～ix) and Fig.

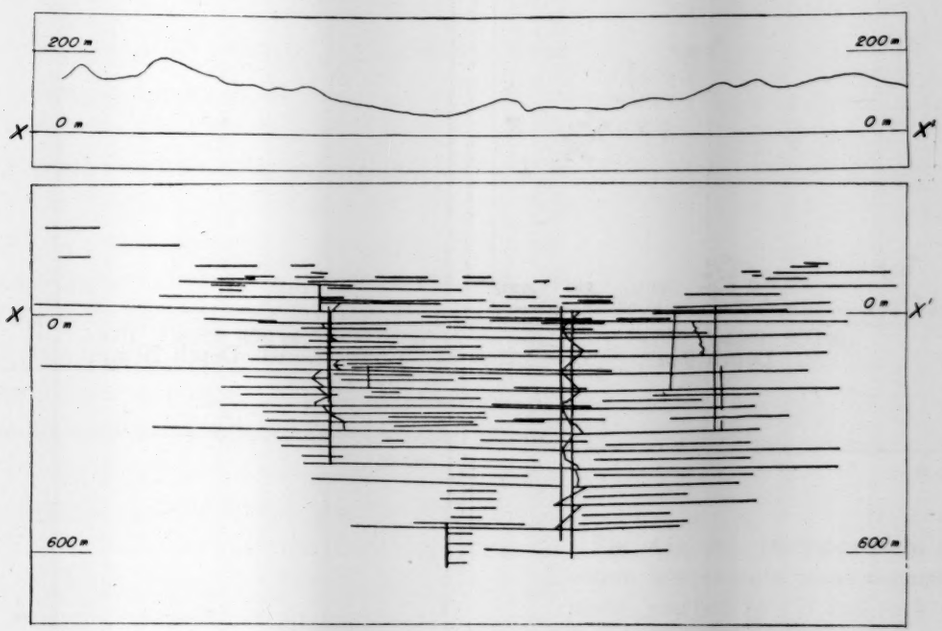


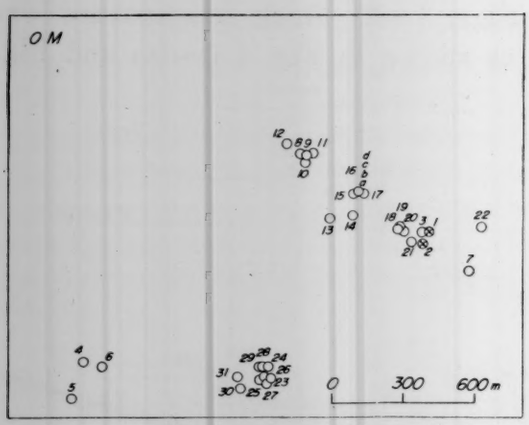

Fig. 3. Vertical section of the mine. The standard level (depth 0 *m*) is 349.6 *m* above sea level.

5. In the figure are also shown the points at which rock specimens were collected.

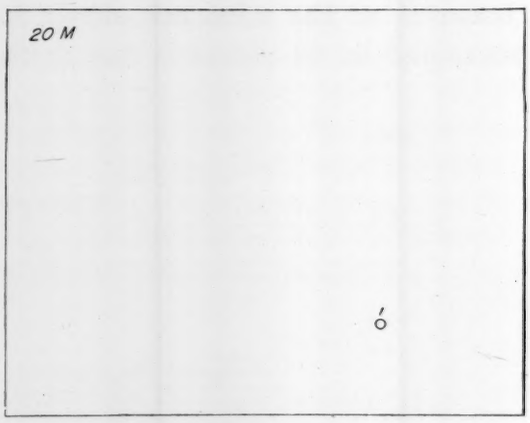
## 2. Thermal Conductivities of Rocks

36 rock specimens were collected from various points in the mine as illustrated in Fig. 4. Attempts were made to collect specimens of the rock species which are predominant in this area. Rocks collected were classified with the aid of a polarizing microscope. For opaque ore specimens a reflecting microscope was used for the purpose. Results of classification are given in Tables 2 and 3. It may be observed in Table 2 that the collected samples of rocks cover rock types well according to the abundance of mother rock types (*cf.* Fig. 12).

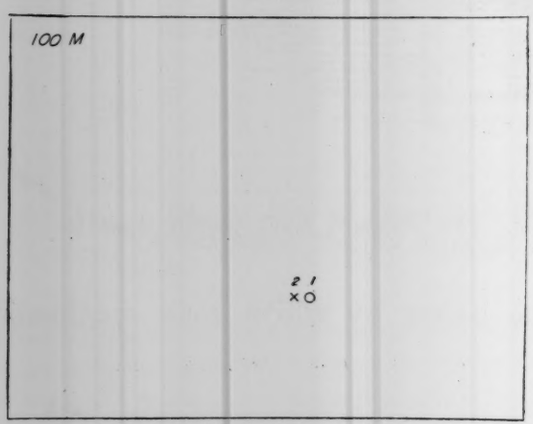
Each specimen of rocks was shaped for measurements as follows. A cylinder about 1 *inch* in diameter was cut out of a specimen by a diamond drill. Then it was cut into three or four disks by a diamond saw to obtain different thicknesses. We regard the specimens to be isotropic in macroscopic nature and do not take into account the



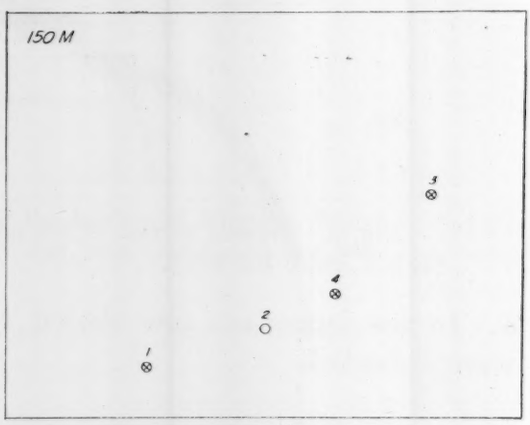

i) Depth 0 *m*.



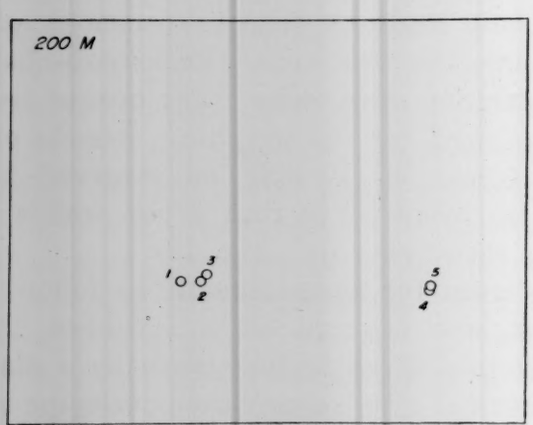

ii) Depth 20 *m*.



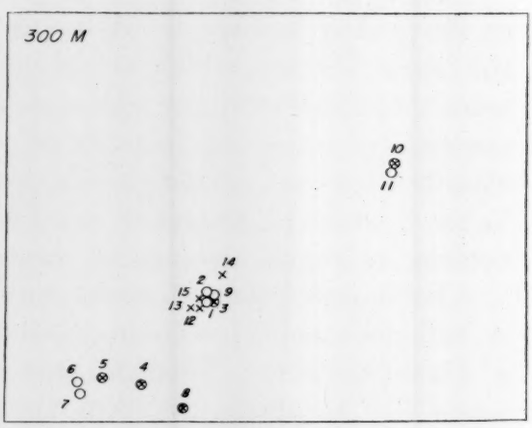

iii) Depth 100 *m*.



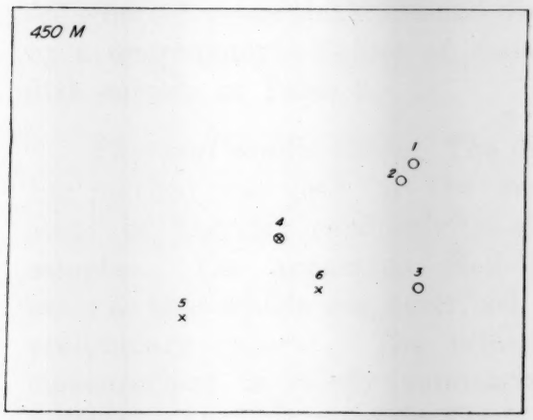

iv) Depth 150 *m*.



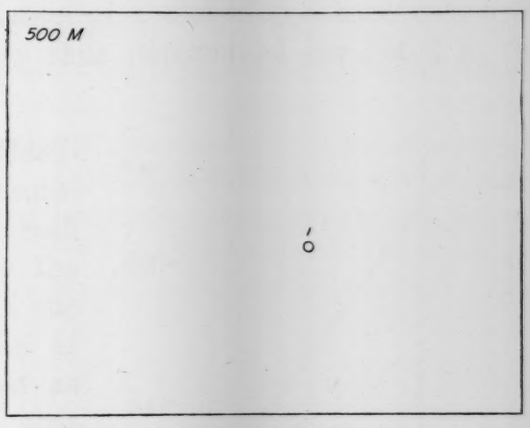

v) Depth 250 *m*.



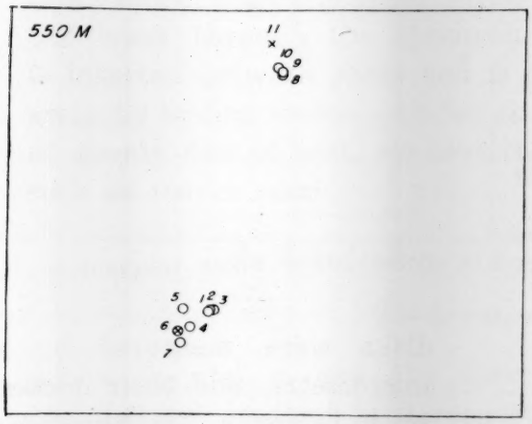

vi) Depth 300 *m*.




vii) Depth 450 *m*.




viii) Depth 500 *m*.




ix) Depth 550 *m*.

Fig. 4 i)~ix) Distribution of points where temperature measurements are made (marked by ○) and rock specimens are collected (marked by ×). The frame of the figures refers to that in Fig. 2.

Table 1. Distribution of points where temperature measurements are made.

| Depth (*m*) | Number of points |
|---|---|
| 0 | 31 |
| 20 | 1 |
| 100 | 1 |
| 150 | 4 |
| 250 | 5 |
| 300 | 11 |
| 450 | 4 |
| 500 | 1 |
| 550 | 10 |
| Total | 68 |

effect of orientation, structure and texture in the direction of cutting. Such an assumption is merely for convenience. In a few exceptional samples, rock specimens are apt to break into pieces along more or less definite breaking planes. In such cases the axis of the cylinder was taken perpendicular to the direction of the planes. The thickness of samples falls usually between 1 *mm* and 8 *mm*. Both the parallel surfaces of each disk were polished by corundum powder on an iron plate. Thicknesses and diameters of these

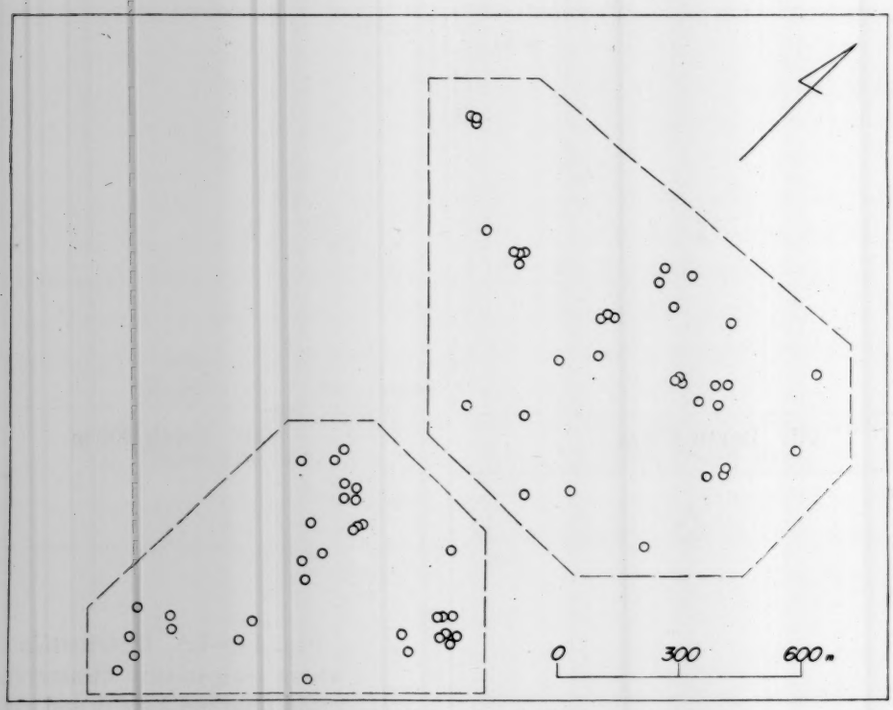



Fig. 5. Projection to the standard level of all the points where temperature measurements are made.

Table 2. Classification of rock specimens.

| Rock type | Number of specimens |
|---|---|
| Hornblende biotite granodiorite | 2 |
| Mica granite<br>Biotite muscovite granite<br>Graphic two mica granite | 4 |
| Biotite amphibole schist<br>Amphibole biotite schist<br>Amphibole schist | 15 |
| Biotite quartz schist<br>Amphibole quartz schist | 3 |
| Sericite schist | 2 |
| Biotite schist<br>Biotite gneiss | 5 |
| Amphibole diabase<br>Epidote schist | 3 |
| Massive chalcopyrite ore<br>Massive cupriferous pyrite ore | 2 |
| Total | 36 |

disks were measured by a micrometer, and their masses by a balance. The thickness within one and the same disked specimen varies usually less than 0.02 $mm$ which is the accuracy of parallelism between the two surfaces. The diameter varies more remarkably. The mass was determined to an order of 0.001 $gm$.

*Density.* Density $\rho$ was determined as a coefficient of linear relation $m=\rho v$ with the aid of the least square method, where $m$ is the mass and $v$ the volume of a specimen. Volume $v$ is given as $v=\pi/4\cdot$

$\delta\phi^2$ where $\delta$, $\phi$ are thickness and diameter of a disked specimen measured by a micrometer. Values of density thus determined are listed in the fifth column of Table 3.

*Thermal conductivity.* The divided-bar method was used for the measurement of thermal conductivity of rock samples. The apparatus used is the same as that which was described in the preliminary report[2]. The principle of measurement is briefly summarized as follows. As illustrated in Fig. 7, heat flows down from the upper brass bar to the lower through the specimen which is inserted between them and is carried away by cooling water. Under the state of steady flow of heat, we have relations such as

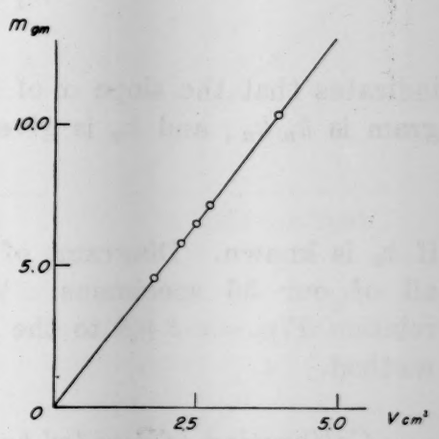



Fig. 6. An example of determination of density. Mass $m$ versus volume $v$ diagram is plotted for a set of specimens. Density $\rho$ is determined as the slope $\rho=m/v$.

$$k_B \cdot p_B = k_R \cdot p_R \qquad (1)$$

$$T = L + p_R \cdot \delta = M \cdot p_B + p_R \cdot \delta \qquad (2)$$

where $k_B$ and $p_B$ are the thermal conductivity of the brass bar and the thermal gradient in it respectively, while $k_R$, $p_R$ are those for the rock specimen. $T$ is the temperature difference between $D$ and $E$ expressed as a sum of $L$ which is the interfacial temperature drop and $p_R \cdot \delta$ the temperature drop in the specimen. $\delta$ is the thickness of the specimen. We assume that the interfacial drop is proportional to the thermal gradient in the brass bar and put $L=M \cdot p_B$, where $M$ denotes the constant of proportionality. In our experiments, a disk-shaped specimen with thickness $\delta$ is inserted between the bars smeared with vaseline to improve the thermal contact at the interfaces and $T$ and $p_B$ are measured in the thermally steady state. The values of $T/p_B$ are plotted against $\delta$ in

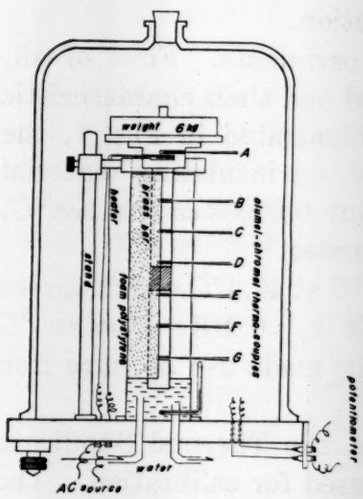



Fig. 7. Sketch of divided-bar apparatus.

2) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *loc. cit.*

a diagram for a set of specimens. Then thermal conductivity is determined as follows. As derived from (1) and (2), the relation

$$T/p_B = M + \frac{k_B}{k_R} \cdot \delta \ , \qquad (3)$$

indicates that the slope $\alpha$ of a curve plotted in the $T/p_B$ versus $\delta$ diagram is $k_B/k_R$, and $k_R$ is given at once by

$$k_R = k_B/\alpha \ ,$$

if $k_B$ is known. Diagrams of $T/p_B - \delta$ relation are given in Fig. 8 for all of our 36 specimens. Values of $\alpha$ are determined by fitting the relation $T/p_B = \alpha \cdot \delta + \beta$ to the diagrams with the aid of the least square method.

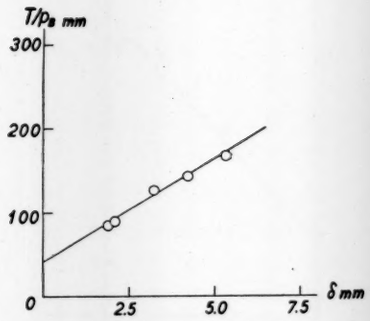
*Calibration of divided-bar apparatus.* To measure the conductivity of the brass bar $k_B$, crystalline quartz and fused quartz were used as standard substances. Two disked crystalline quartz specimens manufactured by the Quartz Crystal Co. of New Malden, Surrey, England were used. They are 2.128 *mm* and 4.143 *mm* in thickness respectively. They were cut so that heat flows in a direction normal to the optic axis and were assumed to have a thermal conductivity $k = 1/60.7 + 0.242\,t$ *cal/cm sec* °*C*[3], where $t$ denotes temperature in centigrade. They were placed in place of rock specimens and $k_B$ was determined by the process just reverse to what has been stated in the last section.

Special care was taken in conducting the experiments. First of all, thermometers B, C, D, E, F and G were calibrated and their characteristic curves were renewed. In the next place, as illustrated in Fig. 7, the brass bars were jacketed with *foam polystyrene*, an insulating material whose thermal conductivity is as low as about 0.00008 *cal/cm sec* °*C*. This material was used to reduce lateral heat losses.

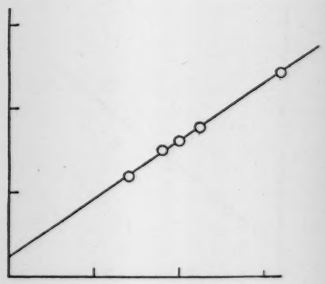
The measurements gave $k_B = 0.219$ *cal/cm sec* °*C* at 40.3°*C* which agrees with an accuracy of 1% with the former result $k_B = 0.218$ *cal/cm sec* °*C* at 20°*C* which was obtained by Uyeda *et al.* who made use of pure iron as the standard[4].

Three fused quartz disks purchased from the Thermal Syndicate Ltd. of Wallsend-on-Tyne, England, were also used for calibration. The thermal conductivity of fused quartz is assumed to be $10^7 k = 31600 + 46\,t$

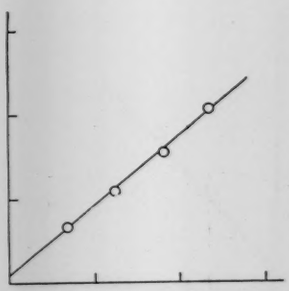
3) E. H. RATCLIFFE, *British Journal of Applied Physics*, **10** (1959), 22.
4) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *loc. cit.*



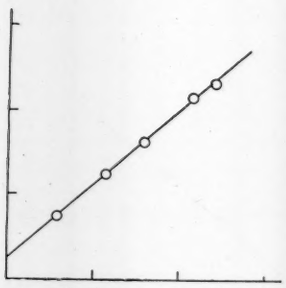

(I) $\alpha=24.03$



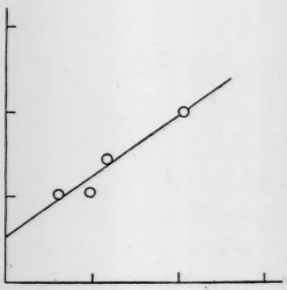
(II) $\alpha=28.04$



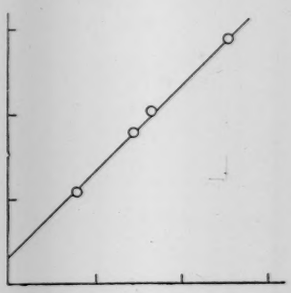
(III) $\alpha=33.06$



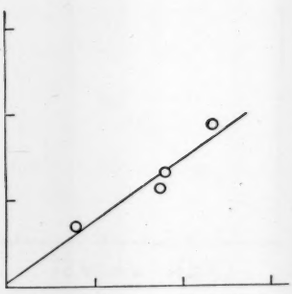
(IV) $\alpha=35.05$



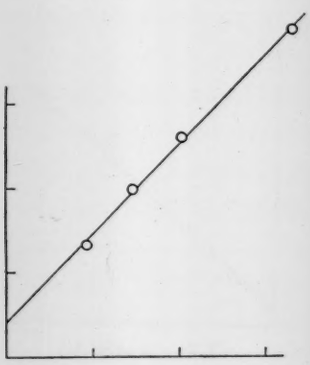
(V) $\alpha=28.82$



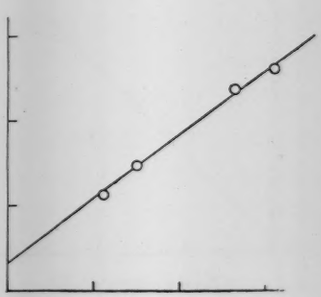
(VI) $\alpha=39.69$



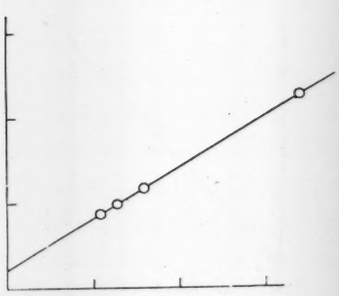
(VII) $\alpha=28.83$



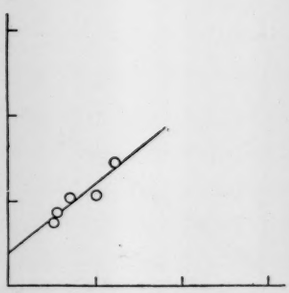
(VIII) $\alpha=41.89$



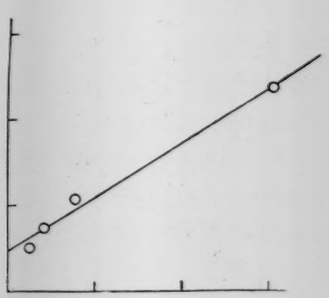
(IX) $\alpha=30.49$



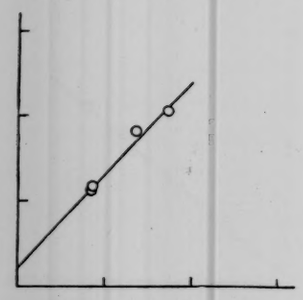
(X) $\alpha=24\ 01$



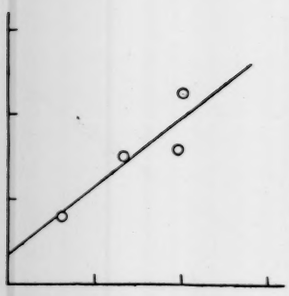
(XI) $\alpha=32.55$



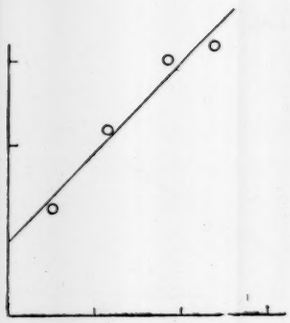
(XII) $\alpha=25.41$



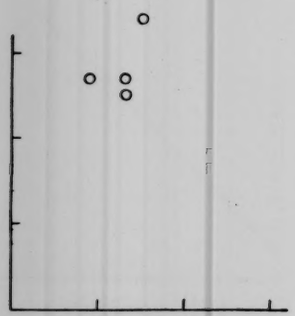
(XIII) $\alpha$=43. 75



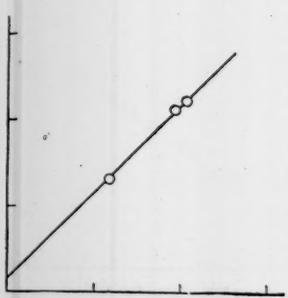
(XIV) $\alpha$=31.95



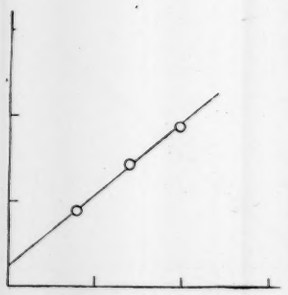
(XV) $\alpha$=42.17



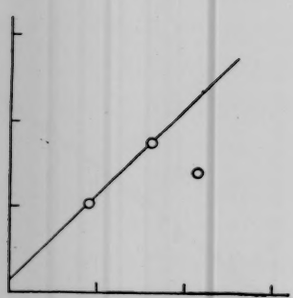
(XVI)



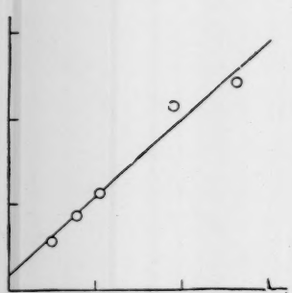
(XVII) $\alpha$=40.66



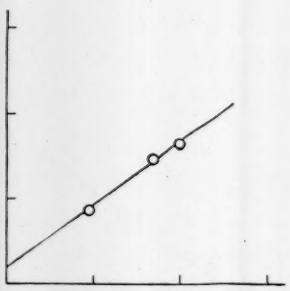
(XVIII) $\alpha$=33.82



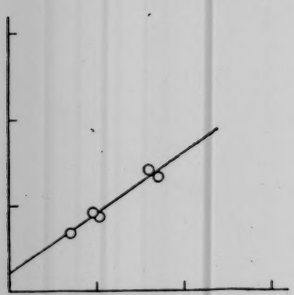
(XIX) $\alpha$=40.10



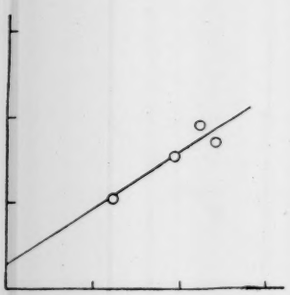
(XX) $\alpha$=36.93



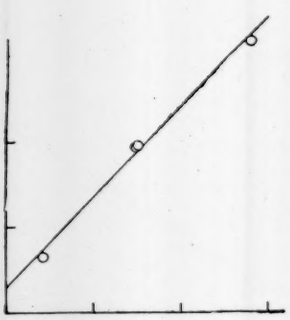
(XXI) $\alpha$=29.51



(XXII) $\alpha$=27.76



(XXIII) $\alpha$=26.19



(XXIV) $\alpha$=42.13

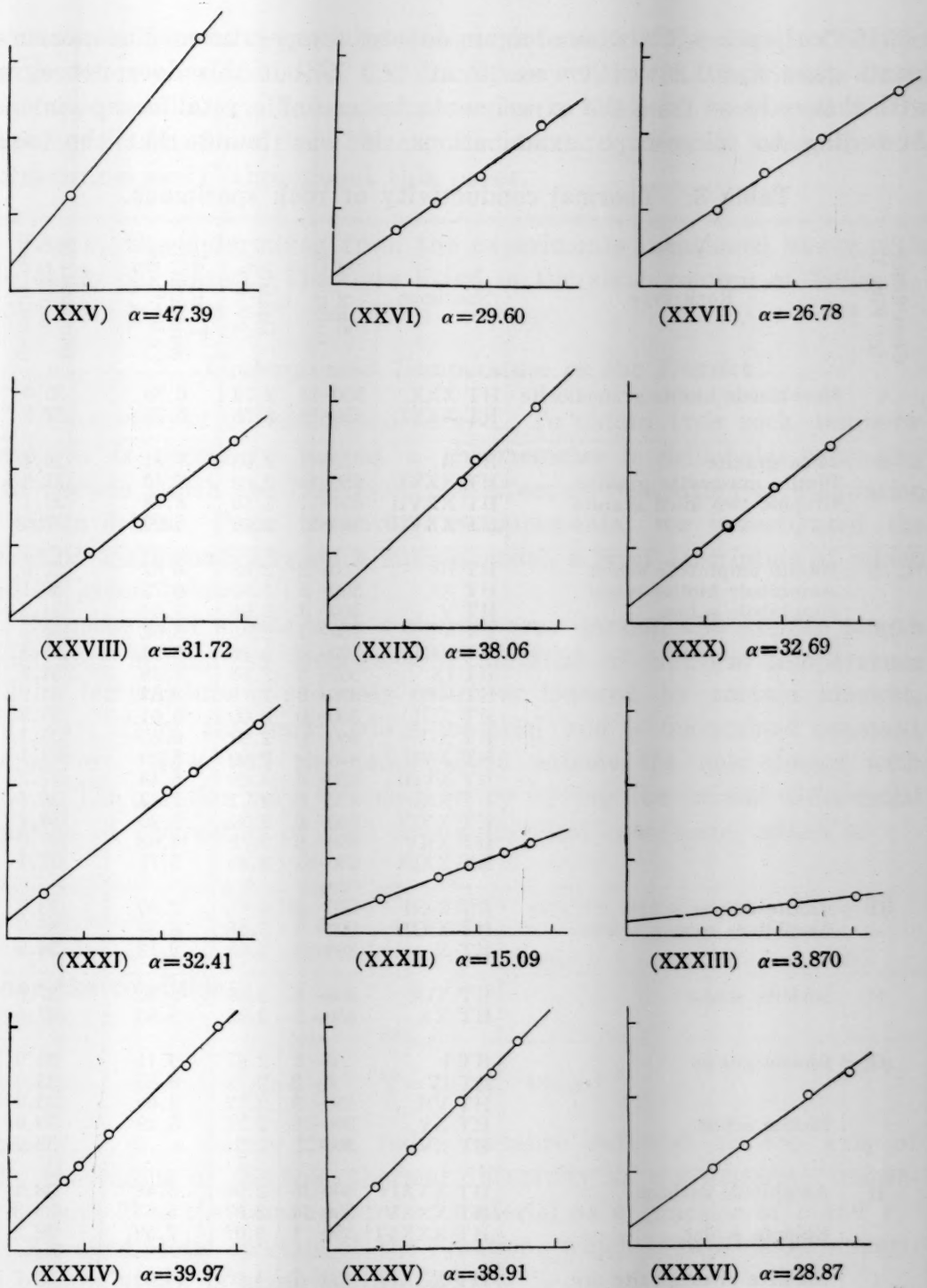



Fig. 8. $T/p_B$ versus $\delta$ diagrams for all 36 rock specimens.
Unit: ordinate $(T/p_B)$.....100 *mm*
abscissa $(\delta)$ .....2.5 *mm*

$-0.16\,t^2\ cal/cm\ sec\ °C$[5] where $t$ again denotes temperature. The measurements gave $k_B=0.201\ cal/cm\ sec\ °C$ at 42.5 °C but this does not agree with that reduced from the experiments by use of crystalline specimens. According to microscope examinations, it was found that the fused

Table 3. Thermal conductivity of rock specimens.

| Classification (*cf* Fig. 12) | Rock type | Specimen | Spot of collection | Density ($gm/cm^3$) | Thermal conductivity ($\times 10^{-3}$ *cal/cm sec° C*) | Mean temperature during measurement (°C) |
|---|---|---|---|---|---|---|
| A | Hornblende biotite granodiorite | HT XXX | 550–11 | 2.73 | 6.70 | 35.0 |
| | | HT XXXI | 550–11 | 2.75 | 6.76 | 37.5 |
| B | Mica granite | HT II | 0– 1 | 2.60 | 7.81 | 26.4 |
| | Biotite muscovite granite | HT XXVI | 550–11 | 2.62 | 7.40 | 37.5 |
| | Graphic two mica granite | HT XXVII | 550–11 | 2.58 | 8.18 | 35.1 |
| | | HT XXVIII | 550–11 | 2.60 | 6.90 | 37.6 |
| C, E | Biotite amphibole schist | HT III | 0– 2 | 2.88 | 6.62 | 27.0 |
| | Amphibole biotite schist | HT XI | 300– 5 | 2.69 | 6.73 | 36.1 |
| | Amphibole schist | HT V | 100– 1 | 2.96 | 7.60 | 34.2 |
| | | HT VI | 150– 1 | 2.86 | 5.52 | 34.2 |
| | | HT VIII | 150– 4 | 2.86 | 5.23 | 33.8 |
| | | HT IX | 300– 3 | 2.83 | 7.18 | 34.7 |
| | | HT XII | 300– 8 | 2.75 | 8.62 | 34.9 |
| | | HT XIII | 300–10 | 3.00 | 5.01 | 35.3 |
| | | HT XIV | 300–10 | 2.97 | 6.85 | 35.1 |
| | | HT XVII | 450– 4 | 2.92 | 5.39 | 37.1 |
| | | HT XVIII | 450– 4 | 3.09 | 6.48 | 37.2 |
| | | HT XXI | 450– 6 | 2.72 | 7.42 | 36.4 |
| | | HT XXIV | 550– 6 | 2.92 | 5.20 | 38.7 |
| | | HT XXV | 550– 6 | 2.88 | 4.62 | 37.0 |
| | | HT XXIX | 550–11 | 2.85 | 5.75 | 37.1 |
| D | Biotite quartz schist | HT XXII | 500– 1 | 2.66 | 7.89 | 33.8 |
| | Amphibole quartz schist | HT XXIII | 500– 1 | 2.66 | 8.36 | 35.0 |
| | | HT X | 300–14 | 2.69 | 9.12 | 34.5 |
| F | Sericite schist | HT XIX | 450– 5 | 2.68 | 5.46 | 37.8 |
| | | HT XX | 450– 5 | 2.68 | 5.93 | 37.5 |
| G | Biotite gneiss | HT I | 0– 1 | 2.67 | 9.11 | 25.9 |
| | | HT IV | 0– 2 | 2.78 | 6.25 | 33.0 |
| | | HT VII | 150– 3 | 2.72 | 7.60 | 33.2 |
| | Biotite schist | HT XV | 300–12 | 2.72 | 5.19 | 39.0 |
| | | HT XVI | 300–12 | 2.61 | | 38.7 |
| H | Amphibole diabase | HT XXXIV | 300–15 | 2.96 | 5.48 | 38.1 |
| | | HT XXXV | 300–14 | 2.97 | 5.63 | 39.3 |
| | Epidote schist | HT XXXVI | 350– 1 | 3.07 | 7.59 | 38.2 |
| I | Massive chalcopyrite ore | HT XXXII | 450– 7 | 4.05 | 14.51 | 35.7 |
| | Massive cupriferous pyrite ore | HT XXXIII | 300–13 | 4.68 | 56.59 | 33.5 |

5) E. H. RATCLIFFE, *loc. cit.*

quartz specimens have partially changed into crystalline state. It might be therefore concluded that the discrepancy between the results based on fused and crystalline quartz samples is likely to be caused by the impurity in fused quartz. Hence, the standard value is taken as $k_B = 0.219\ cal/cm\ sec\ °C$ throughout this paper.

As $k_B$ was determined from the experiments mentioned above, $k_R$'s are easily calculated. They are listed in the sixth column of Table 3.

### 3. Underground Temperature of the District

*Measurement of rock temperature.* To obtain true rock temperatures, it is necessary to put a thermometer in drill holes extending into regions which are free from the effect of ventilation or stagnation of air in drifts. Prior to actual measurements, we investigated the situation mathematically on a simple model, a brief description of which will be given below.

Suppose that a hole with a circular cross section and infinite length penetrates an infinite homogeneous material of uniform temperature and its temperature is suddenly raised or lowered by certain amount, $1\ °C$ say, from the surrounding material and is maintained constant thereafter. How will the temperature outside the hole change with time? The question may be answered by solving the partial differential equation of conduction of heat in a cylindrical coordinate, which is

$$\frac{\partial T}{\partial t} = \kappa\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right), \quad a \leq r \leq \infty , \tag{4}$$

under the conditions

$$\left.\begin{aligned} t=0 &: \quad T=0 \\ t>0 &: \quad T=1 \quad \text{at} \quad r=a \end{aligned}\right\}, \tag{5}$$

where $t$, $r$, $a$, $\kappa$ denote time, radial distance referred to the axis of hole, the radius of the hole, thermal diffusivity of the material, respectively and $T$ is the tempepature of material as a function of $t$ and $r$.

An asymptotic solution of the equation, which is capable of numerical manipulation, is given in the form[6]

6) H. S. CARSLAW and J. C. JAEGER, *Conduction of Heat in Solids* (Oxford at the Clarendon Press, 1950), § 127.

$$T=\frac{a^{1/2}}{r^{1/2}}erfc\frac{r-a}{2\sqrt{\kappa t}}+\frac{(r-a)(\kappa t)^{1/2}}{4a^{1/2}r^{3/2}}ierfc\frac{r-a}{2\sqrt{\kappa t}}$$
$$+\frac{(9a^2-2ar-7r^2)\kappa t}{32a^{3/2}r^{5/2}}i^2erfc\frac{r-a}{2\sqrt{\kappa t}}+\cdots . \qquad (6)$$

The first term of it, which satisfies the imposed conditions (5) by itself, substituted into equation (4) yields for the left-hand side

$$\frac{\partial T}{\partial t}=\frac{2}{\sqrt{\pi}}\left\{\sqrt{\frac{a}{r}}\frac{r-a}{4\sqrt{\kappa}\,t^{3/2}}e^{-\frac{(r-a)^2}{4\kappa t}}\right\}, \qquad (7)$$

and for the right-hand side

$$\kappa\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)=\frac{2}{\sqrt{\pi}}\left\{\sqrt{\frac{a}{r}}\frac{r-a}{4\sqrt{\kappa}\,t^{3/2}}e^{-\frac{(r-a)^2}{4\kappa t}}\right\}$$
$$+\frac{\sqrt{a}\,\kappa}{4r^{5/2}}\left(1-erf\frac{r-a}{2\sqrt{\kappa t}}\right). \qquad (8)$$

For the case in which we are concerned ($t\geq 3\times 10^7\,sec$, $r\geq 10^2\,cm$, $\kappa\simeq 10^{-2}\,cm^2/sec$), the additional term in (8), $10^{-6}\,c.g.s.$ in order, compared to the first term of (6), $1\,c.g.s.$ in order, assures us that we can adopt

$$T=\sqrt{\frac{a}{r}}\,erfc\,\frac{r-a}{2\sqrt{\kappa t}}, \qquad (9)$$

as an approximate solution of the problem.

In virtue of the solution (9), the distance necessary for the temperature to fall by some extent, 10 and 1% say, can be calculated.

Table 4. Distance required to diminish the effect to 10% and to 1%. $\kappa=1.09\times 10^{-2}\,cm^2/sec$ ($k=5.3\times 10^{-3}\,cal/cm\,sec\,°C$, $c=0.18\,cal/gm\,°C$, $\rho=2.70\,gm/cm^3$) and $a=1\,m$ are assumed tentatively.

| $t$ | $r(T\lesssim 0.1)$ | $r(T\lesssim 0.01)$ |
|---|---|---|
| 6 *months* | 8 *m* | 14 *m* |
| 1 *year* | 10 | 18 |
| 5 *years* | 17 | 36 |
| 10 *years* | 21 | 49 |
| 50 *years* | 34 | 98 |
| 100 *years* | 41 | 132 |

Some numerical examples are given for various time epochs as are shown in Table 4.

It is suggested from the above calculation, that we may measure temperatures at points of every 1 or 2 $m$ along a drill hole to see how far the effect really extends. The results are shown in Fig. 9 in which a calculated value is also shown for comparison. Though a definite correspondence between observed and calculated results is not recognizable, the investigation assured us that insertion of thermometer as deep as 20 $m$ in holes is practically sufficient for observing true rock temperature.

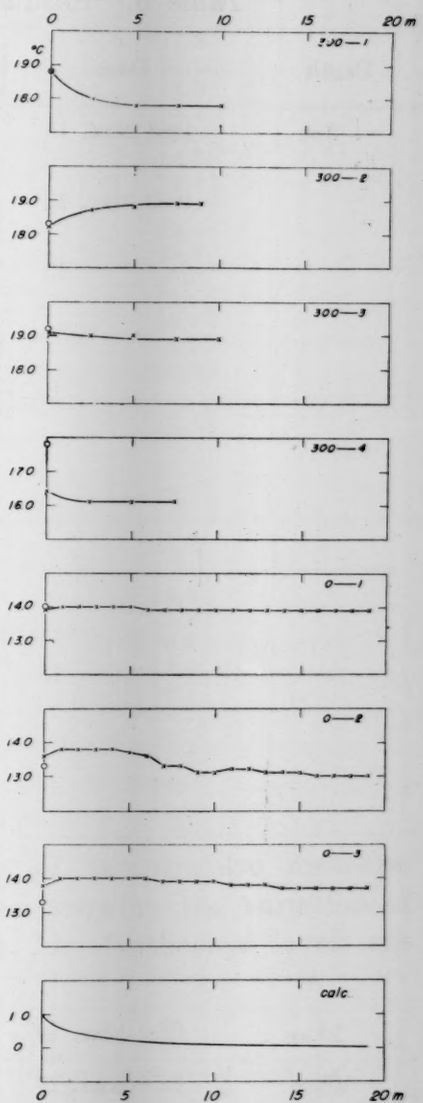



Fig. 9. Temperature variation in drill holes. Mark ○ denotes the temperature of the air in the drift near the opening of the hole. Calculated example is given for the case $t=1$ *year*, $\kappa=1.09\times10^{-2}$ *cm*²/*sec*, $a=1$ *m*.

Temperature measurements were made as follows. A thermister sealed in a pressure- and water-proof container was fixed to the top of an aluminium rod and was inserted into the hole and then another rod was joined to it which pushed the thermometer a little further. This process was repeated untill the thermometer reached the required position, for example 20 $m$ distant from the opening, and the temperature was read by a portable potentiometer (connected to the thermometer with a water-proof lead wire) after the thermometer reached the state of thermal equilibrium. The thermister was calibrated in the laboratory before and after the measurements by a standard mercury-in-glass thermometer to the accuracy of 0.1°$C$.

Drill holes used are those which had been made for the purpose of searching for a vein of ore, whose diameters are about 1 *inch* and lengths extend usually some hundred meters. There were 835 such holes in the spring of 1959, but only 68 of them were usable for the measurements.

Results of measurements for all these 68 holes are tabulated in Table 5.

Table 5. Result of temperature measurement.

| Depth | Date | No. | Length of insertion | Temperature | Note |
|---|---|---|---|---|---|
| 0 *m* | 1958 Nov. 15 | 1 | 19*m* | 13.9 °*C* | |
| | | 2 | 19 | 13.0 | |
| | | 3 | 19 | 13.7 | |
| | 1959 Mar. 13 | 1 | 20 | 14.1 | |
| | | 2 | 20 | 13.3 | |
| | | 3 | 20 | 12.8 | |
| | 12 | 4 | 20 | 12.0 | |
| | | 5 | 20 | 12.7 | |
| | | 6 | 20 | 12.5 | |
| | | 7 | 3.9 | 21.4 | |
| | | 8 | 20 | 12.3 | |
| | | 9 | 10 | 12.4 | |
| | | 10 | 20 | 12.3 | |
| | | 11 | 20 | 12.4 | |
| | | 12 | 20 | 11.5 | |
| | | 13 | 20 | 12.6 | |
| | | 14 | 20 | 12.6 | |
| | | 15 | 20 | 12.3 | |
| | | 16 a | 20 | 12.2 | |
| | | 16 b | 30 | 12.2 | |
| | | 16 c | 40 | 12.2 | |
| | | 16 d | 50 | 12.2 | |
| | | 17 | 20 | 12.3 | |
| | 13 | 18 | 20 | 12.5 | |
| | | 19 | 20 | 12.7 | |
| | | 20 | 15.3 | 12.7 | |
| | | 21 | 9.2 | 12.7 | |
| | | 22 | 20 | 12.2 | |
| | | 23 | 20 | 12.3 | |
| | | 24 | 20 | 12.5 | |
| | | 25 | 20 | 12.5 | |
| | | 26 | 18 | 12.3 | |
| | | 27 | 20 | 12.4 | |
| | | 28 | 20 | 12.4 | |
| | | 29 | 17.3 | 12.8 | |
| | | 30 | 20 | 12.9 | |
| | | 31 | 20 | 13.7 | |
| 20 *m* | 1959 Mar. 19 | 1 | 20 | 12.1 | |
| 100 *m* | 1959 Mar. 19 | 1 | 3.3 | 14.2 | |
| 150 *m* | 1959 Mar. 14 | 1 | 20 | 15.2 | |
| | | 2 | 7.3 | 14.0 | |
| | | 3 | 8 | 13.1 | |
| | | 4 | 12.6 | 16.5 | |
| 250 *m* | 1959 Mar. 19 | 1 | 20 | 15.1 | |
| | | 2 | 11.3 | 18.0 | |
| | | 3 | 16 | 21.8 | |
| | 20 | 4 | 15 | 23.4 | |
| | | 5 | 20 | 24.6 | |

(to be continued)

Table 5. Result of temperature measurement. (continued)

| Depth | Date | No. | Length of insertion | Temperature | Note |
|---|---|---|---|---|---|
| 300 *m* | 1958 Nov. 14 | 1 | 10 | 17.8 | |
| | | 2 | 8.9 | 18.9 | |
| | | 3 | 10 | 18.9 | |
| | | 4 | 7.5 | 16.1 | |
| | 1959 Mar. 16 | 1 | 20 | 17.3 | |
| | | 2 | 12 | 18.6 | |
| | | 3 | 20 | 18.4 | |
| | | 4 | 14 | 16.0 | |
| | | 5 | 20 | 15.9 | |
| | | 6 | 20 | 15.8 | |
| | | 7 | 20 | 16.0 | |
| | | 8 | 20 | 15.8 | |
| | | 9 | 7 | 20.7 | |
| | | 10 | 4.3 | 14.5 | |
| | | 11 | 20 | 14.8 | |
| 450 *m* | 1959 Mar. 17 | 1 | 20 | 16.4 | |
| | | 2 | 20 | 16.5 | |
| | | 3 | 20 | 17.2 | |
| | | 4 | 3 | 16.7 | |
| 500 *m* | 1959 Mar. 18 | 1 | 20 | 17.3 | |
| 550 *m* | 1959 Mar. 18 | 1 | 20 | 19.3 | |
| | | 2 | 20 | 19.3 | |
| | | 3 | 20 | 19.2 | |
| | | 4 | 20 | 19.4 | |
| | | 5 | 20 | 19.3 | |
| | | 6 | 20 | 19.2 | |
| | | 7 | 20 | 19.3 | |
| | | 8 | 20 | 17.8 | |
| | | 9 | 20 | 18.0 | |
| | | 10 | 20 | 17.9 | |

*Temperature gradient.* All the results of temperature measurements were projected to the vertical section showing the variation of subsurface temperature as illustrated in Fig. 10. Isothermal levels are

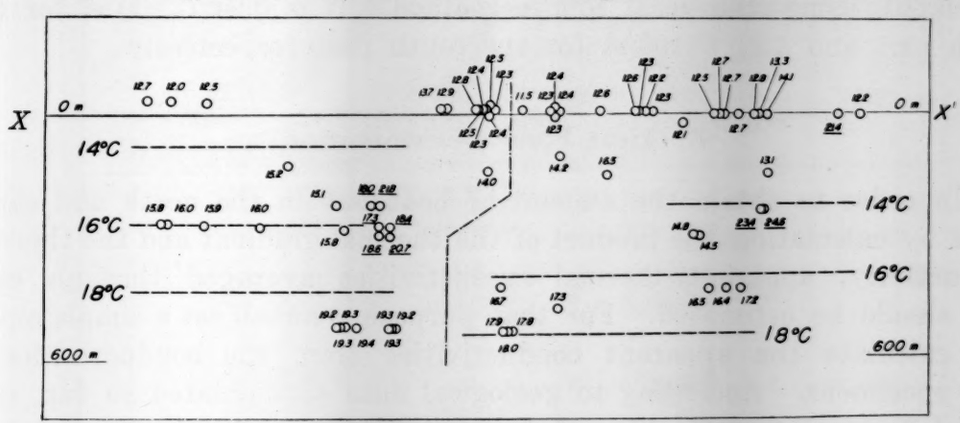



Fig. 10. Variation of underground isotherms projected to the vertical section X–X'.

found to be nearly horizontal showing that the geothermal heat flows nearly vertically in this region. In order to smooth out the isothermal curves, 9 points (marked by underlines) out of 68 are neglected because they are considered to be local anomalies due probably to the heat of oxidation. Difference of isothermal levels between the north and south parts becomes clear when it is represented by the avarage temperature gradients as can be seen in Fig. 11. The average temperature gradients were

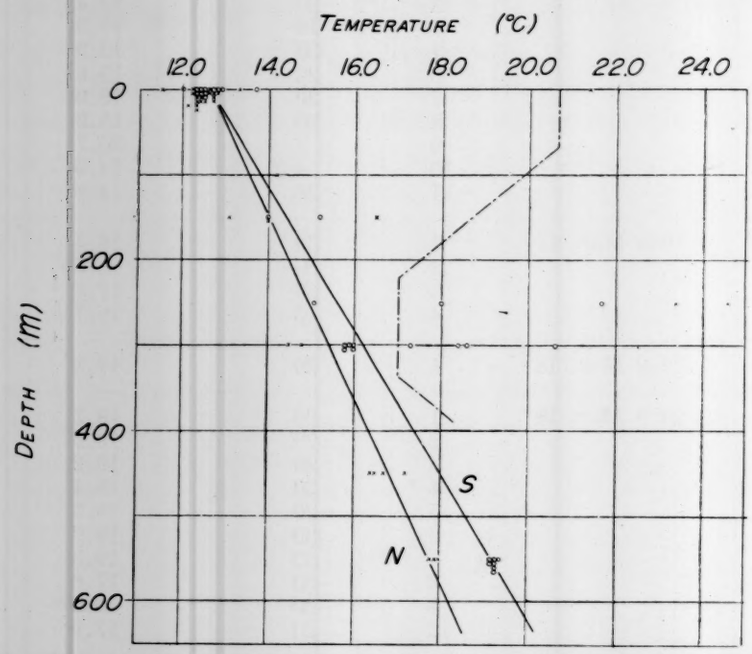



Fig. 11. Average temperature gradients for the north and south parts. Mark × is for the north part and ○ for the south part. The exceptional 9 points are bracketed by a chain line.

calculated using the least square method. It is $0.94°C/100\,m$ for the north part and $1.21°C/100\,m$ for the south part respectively.

## 4. Heat Flow Determination

In order to obtain the amount of heat flow in the north and south parts by calculating the product of the thermal gradient and the thermal conductivity, apparent thermal conductivities averaged through each part should be estimated. For that purpose we shall set a simple model and calculate the apparent conductivities from the conductivities of rock specimens. According to geological data accumulated so far, geological features are all alike whatever underground level we may take

as far as underground structures not deeper than several hundred meters are concerned. It is then possible to idealize the structure of the region under investigation to be composed of columns of different rock types in which heat flows to the direction parallel to the axis of columns. On this assumption the bulk thermal conductivity of a volume composed of many columns of different conductivity can be calculated in the following way. Let $Q_i$ be the heat flow per unit time across a section of $i$'th column whose area of section is $S_i$ and thermal conductivity is $k_i$. Then the relation $Q_i = S_i \cdot k_i(\Delta T/\Delta l)$ holds provided the temperature gradient $\Delta T/\Delta l$ is the same for all columns. The total flow of heat is given as $Q = \sum Q_i = \sum(S_i k_i/S) \cdot S(\Delta T/\Delta l)$, so that $k = \sum(S_i/S)k_i$ is the apparent thermal conductivity averaged through the volume, where $S = \sum S_i$.

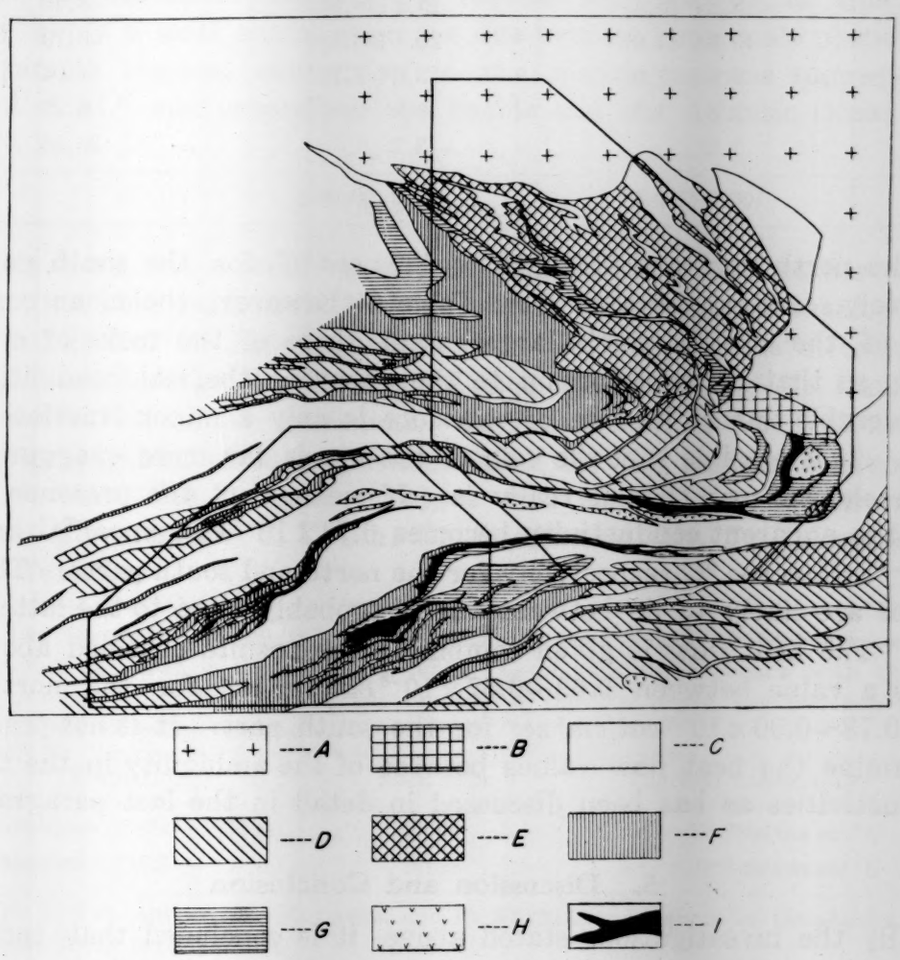



Fig. 12. Geological map of the area under investigation.

Planimetry was carried out on the geological map which was supplied by the courtesy of the Department of Geophysical Prospecting of the Hitachi Mine, Nihon Kogyo Co. (Fig. 12). The result is shown in Table 6. Combining it with the mean thermal conductivities of rocks, the apparent thermal conductivities are obtained, *i.e.* $7.08\times10^{-3}$ *cal/cm sec* °*C*

Table 6. Result of planimetry and the mean thermal conductivity of rocks.

| | North part (0.918 $km^2$) | South part (0.508 $km^2$) | Mean thermal conductivity ($\times10^{-3}$ *cal/cm sec* °*C*) |
|---|---|---|---|
| A | 16.8 ( 17.0) | | 6.73 |
| B | 2.2 ( 2.2) | | 7.57 |
| C, E | 44.1 ( 44.6) | 54.0 (55.8) | 6.28 |
| D | 16.2 ( 16.4) | 15.1 (15.6) | 8.46 |
| F | 10.9 ( 11.0) | 23.1 (23.9) | 5.70 |
| G | 6.9 ( 7.0) | 3.6 ( 3.7) | 7.04 |
| H | 1.8 ( 1.8) | 0.9 ( 0.9) | 6.23 |
| I | 1.2 | 3.2 | 35.55 |
| | 100.1 (100.0) | 99.9 (99.9) | |

for the north part and $7.43\times10^{-3}$ *cal/cm sec* °*C* for the south part respectively. As can be seen from Table 6, however, the mean conductivity of the ore is much larger than those of the rocks of ordinary types, so that its contribution to the apparent thermal conductivity is considerable though its area of exposure is only a minor fraction of the total. It is possible that the vein of the ore is far more exaggerated in the geological map than it really is. If we neglect the presence of the ore, the apparent conductivity becomes $6.73\times10^{-3}$ *cal/cm sec* °*C* and $6.50\times10^{-3}$ *cal/cm* sec °*C* respectively for the north and south parts. The true values are likely to lie between them, probably close to the latter ones.

The heat flow is given combining the results obtained above. It takes a value between $0.63\sim0.67\times10^{-6}$ *cal/cm² sec* for the north part and $0.78\sim0.90\times10^{-6}$ *cal/cm² sec* for the south part. It is not possible to determine the heat flow values because of the ambiguity in the thermal conductivities as has been discussed in detail in the last paragraph.

## 5. Discussion and Conclusion

By the investigations stated above, it is concluded that terrestrial heat flow at the Hitachi Mine takes a value between $0.63\sim0.67\times10^{-6}$

$cal/cm^2\,sec$ for the north part and $0.78\sim0.90\times10^{-6}\,cal/cm^2\,sec$ for the south part. They are definitely smaller than the values at Sasago reported in the first paper *i.e.* $2.06\times10^{-6}\,cal/cm^2\,sec$, at Yabase oil field[7] *i.e.* $2.01\times10^{-6}\,cal/cm^2\,sec$ or the global average $1.20\times10^{-6}\,cal/cm^2\,sec$. Contrary to the remarks stated in the first paper that physical and chemical processes in the crust accompanying orogenetic activity of Circum-Pacific Orogenetic Belts will cause greater heat flow in Japan, it is important that we have observed very low values of heat flow at Hitachi. At the moment, it is difficult to see the reason why such a small heat flow is observed here. Apart from further correction for possible effects of pressure, temperature and water content on the thermal conductivity of rock or effect of underground circulating water on the geothermal gradient, it will require some more laborious accumulation of data to clarify the question whether the results we obtained in this paper merely imply a local anomaly or are due to some large scale phenomena, for example thermal convection in the mantle as was suggested by Bullard *et al.*[8] and others[9] in the Pacific and the Atlantic Oceans.

## 6. Acknowledgement

This work was directed by Dr. T. Rikitake and the author thanks him for his kind guidance. He also wishes to express his thank to Professor C. Tsuboi for his encouragement. He is also grateful to Professor H. Tsuya for the classification of rock specimens and Mr. Okuno for the classification of ore specimens. He is indebted to Mr. T. Watanabe for the preparation of rock specimens used for the thermal conductivity measurements. He also acknowledges with thanks valuable discussion and help given by Dr. S. Uyeda, Dr. S. Akimoto, Mr. T. Yukutake and Mr. I. Tanaoka.

7) The thermal conductivity of rock specimens from Yabase oil field was measured by the author as shown in the following table. Combining these results with the geothermal gradient which has been already reported in the first paper, the heat flow is estimated at $2.01\times10^{-6}cal/cm^2\,sec$ there.

| Formation | Rock type | Thermal conductivity |
|---|---|---|
| Funakawa ( 360~1030 *m*) | Shale | $3.43\times10^{-3}\,cal/cm\,sec\,°C$ |
| Onagawa (1030~ *m*) | Shale | $5.47\times10^{-3}\,cal/cm\,sec\,°C$ |

8) E. C. BULLARD, A. E. MAXWELL and R. REVELLE, *Advances in Geophysics*, (Academic Press Inc.), **3** (1956), 153.

9) R. VON HERZEN, *Nature*, **183** (1959) *No.* 4665, 882.

Finally the author wishes to express his sincere thanks to the staff of the Hitachi Mine, Nihon Kogyo Co., especially to the members of the Department of Geophysical Prospecting, for without their whole-hearted cooperation and assistance this investigation could not have been completed. Professor Y. Shimomura and Mr. R. Imamura have kindly arranged the work. The author would like to extend his thanks to them.

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## 36. 地球熱学 (第3報)
## 茨城県日立市に於ける地殻内熱流量

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地球物理学専門課程 宝来帰一

茨城県日立市日立鉱山に於ける地下温度勾配及び岩石熱伝導率測定の結果，鉱山の北部及び南部の二地域で温度勾配はそれぞれ 0.94 °C/100 m，1.21 °C/100 m であること及び等温面がほぼ地表面に平行すなわち熱流の方向がほぼ地表面に垂直であることを見出した．又岩石熱伝導率測定値にもとづいて北部及び南部二地域の見かけの熱伝導率は $6.73\sim7.08\times10^{-3}$ cal/cm sec °C 及び $6.51\sim7.43\times10^{-3}$ cal/cm scc °C であると算定された．これによると，地殻内熱流量は北部に於て $0.63\sim0.67\times10^{-6}$ cal/cm³ sec，南部に於て $0.79\sim0.90\times10^{-6}$ cal/cm² sec となるが，この値は第一報に報告された笹子トンネルに於ける結果 $2.06\times10^{-6}$ cal/cm² sec よりも低いのみならず世界の平均とされている $1.20\times10^{-6}$ cal/cm² sec よりもなお低いようである．ここに求められた結果が，地殻内の局地的異常を表わすものか，或いは更に大規模な現象，中間層に於ける熱対流など，に関連あるものであるかどうかを追求するためには，更にこの種の研究の成果の集積をまたねばならない．

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地震研究所彙報
第37号 (1959) 593-608頁

# 37. 紀伊半島の局地地震 (第2報)

## ―震度調査による和歌山県下地震活動の概況―

地震研究所　宮村攝三

(昭和 34 年9月 22 日発表――昭和 34 年9月 30 日受理)

人体感覚にもとづく震度報告により和歌山県下の地震活動状況を調査した結果，和歌山より御坊にいたる海岸地方がもつとも活動的であり，日高川中流，富田川上流および日置川流域にそれぞれやや活動的な場所が推定された．また県の南東部および北東部には局地的地震が非常にすくないこともわかつた．気象庁の地震観測網による験測はこのような局地地震に対してはきわめて不充分であり，区内観測所の震度報告に依存することがおおきいのでその確実な運用がのぞまれる．

### 1. 序　　言

破壊的地震による各地の震動の程度を人体感覚をもとにした震度階によつてあらわし，震央距離による震度の減衰にもとづき，地震の規模や震源深度を決定する根拠とし，あるいはまた震度分布の地形，地質等の影響による異常をしらべて，地震工学上の重要概念であるいわゆる地盤の性質を推定することは，ふるくよりおこなわれ，有益な結果をあげてきた．そして，現在でも地震計による観測網がこのような目的のためにはなおきわめて粗であるため，人体感覚による震度分布の調査は充分有力な研究手段とみられ，しばしば実際におこなわれている．

ところで，大地震の震度分布をしらべる以外にも，人体感覚による震度調査は，今日の常設観測網で充分あきらかにすることのできない各地の地震活動状況をしらべるのに有効であり，気象庁でも区内観測所をかずおおくもうけて，震度報告を依託しており，震源位置決定にも参照しているようである．

和歌山県には県の南北両端の潮岬，和歌山両測候所に地震計があるが，これらのいづれにも記録されない有感地震の報告されることもあり，人体感覚による地震活動調査は，この地方の局地地震の概況をしるひとつの有効な手段であるとおもわれる．

本稿には大阪管区気象台地震月報に報告された資料と，著者が和歌山県の協力をえて実施した 1952 年9月―1953 年2月の調査の結果とを整理して，人体感覚による震度調査にもとづく和歌山県下の地震活動状況の概要を報告する．

### 2. 区内観測所震度報告

和歌山県下の区内観測所は 20 カ所，そのほか，まれに報告をしているが，経常的に活動しているかどうか疑問のものが数カ所ある．区内観測所の報告は当然ながら有感のばあ

いのみであるから，1年に1回も報告がなくても，実際に地震を1回も感じなかつたのか，観測乃至報告をおこたつていたのかは判明しない．奈良県南部にいくつかの区内観測所があるが 1952～1958 の7年間に1回の有感もそこから報告されていない．これは事実とすれば大変興味があるが，重要なことなので，今後の調査をまちたい．

和歌山県下の上述の 20 カ所と和歌山，潮岬の両測候所は 1952～1958 の7年間，まず恒常的に観測をつづけていたとみなせるとして，それらの点での有感地震の回数をしらべたものが，Fig. 1 である．またそのうちで，特定の1点のみで有感であつた地震をしらべると，当然これはその点を中心とし，隣接点とその点とをむすぶ線分の垂直2等分線でかこまれた多角形内の区域に震央のある地震ということができるので，それを各点のまわりの局地的地震活動のめやすとすることができる．そのように1点のみで感じられた地震の1952～1958年間の年平均回数の分布を図示したものが Fig. 2

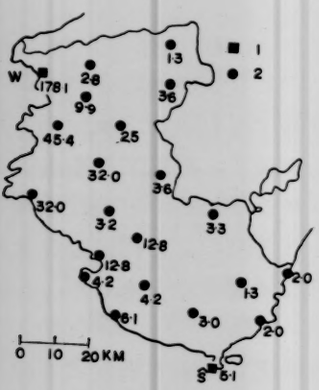


Fig. 1. Annual numbers of earthquakes felt at the J.M.A. weather stations and entrusted substations in Wakayama Prefecture during 1952～1958. (Original data are taken from The Monthly Report of Earthquakes, Osaka District Meteorological Observatory.)
1–Weather station equipped with seismographs. W: Wakayama. Ŝ: Siono-misaki. 2–Entrusted substation reporting earthquake intensities.

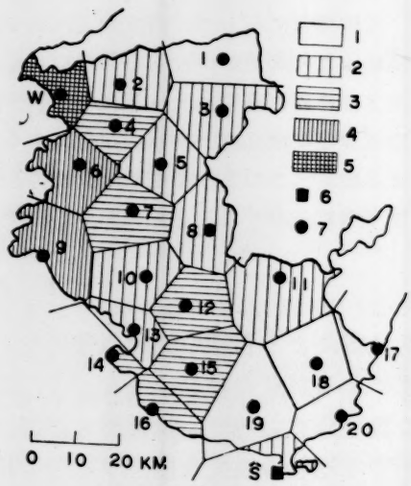


Fig. 2. Distribution of annual numbers, N of earthquakes felt at a single station. 1 –0.0≦N<0.1. 2–0.1≦N<1.0. 3–1≦N<10. 4–10≦N<100. 5–100≦N. 6–Weather station equipped with seismographs. W: Wakayama, N=105.3. Ŝ: Siono-misaki, N=0.3. 7–Entrusted substation reporting earthquake intensities. 1: Oki, N=0.0. 2: Iwade, N=0.2. 3: Koyasan, N=0.4. 4: Higasi-nokami, N=2.6. 5: Yahata, N=0.8. 6: Tadono, N=19.4 7: Kawakami, N=3.3. 8: Ryuzin, N=0.8. 9: Gobo, N=13.0. 10: Kiyokawa, N=0.5. 11: Misato, N=0.5. 12: Kurusugawa, N=2.4. 13: Tanabe, N=0.2 14: Sirahama, N=5.0. 15: Itikano, N=1.3. 16: Hiki, N=1.3. 17: Singu, N=0.0. 18: Irokawa, N=0.0. 19: Sitikawa, N=0.0. 20: Simosato, N=0.0.

であり，もつともはげしい局所的小地震の活動は和歌山市附近にあり，ついでその南方の有田川河口より日高川河口御坊附近までの海岸地方がそのような局地地震の活動中心であることが明示されている．さらに，川上を中心とする日高川中流，栗栖川を中心とする富

田川中流，日置，市鹿野を中心とする日置川流域にも，それぞれやや独立した局地地震の活動がみられることもうかがえる．一方，県の北東隅伊都郡方面と，南東隅東牟婁郡方面とではその地方だけに有感というような局地的な小地震はほとんど発生していない．これらの部分は現在ほとんど局地地震活動のない地域ということができよう．

Fig. 3 は 1952～1958 年における気象庁により震源決定のなされた地震数をその震央位置に記入したもので，括弧したものは深度 50 km 以上のふかい地殻下の地震である．こうした計測結果からえたややつよい地震の震央分布と，区内観測所の有感報告からえた局地的小地震の分布とは，大勢においてよく一致しているが，日高川上流竜神附近に計測による震央がおおいこと，富田川中流に計測による震央がすくないことなどが，相異といえばいえる．

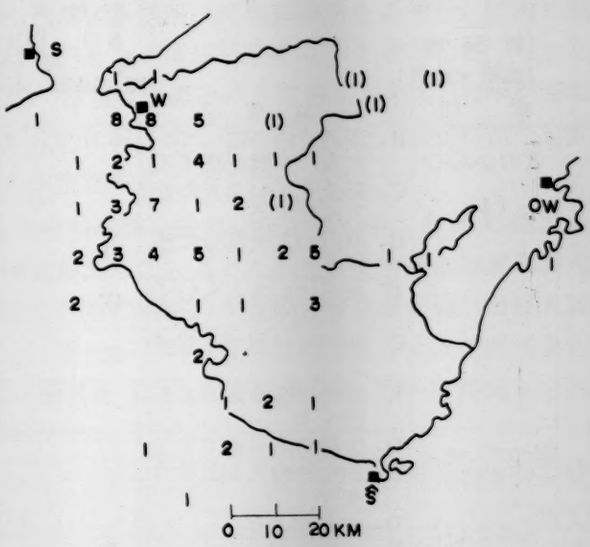


Fig. 3. Numbers of epicenters determined seismometrically by J.M.A. in Kii Peninsula for 1952～1958. Numbers in parentheses are for subcrustal earthquakes. Weather stations equipped with seismographs in the region are as follows: S–Sumoto, W–Wakayama, Ŝ–Sionomisaki, Ow–Owase.

### 3. 震度調査表

1952 年秋に地震計による臨時精密観測をおこなうにさきだち，下記のような調査表を県下諸方面に配布して，震度報告調査による局地地震活動状況の偵察をこころみた．

調査表は佐藤泰夫が大地震の震度分布通信調査における低震度用につくつた規準で，現在の気象庁震度との対比はほぼ Table 1 のようなものであり，Table 2 のような形式になつている．記入された A, B, C etc. に 1, 2, 3 etc. を，A′, B′, C′ etc. には 1.5, 2.5, 3.5 etc. をあたえ，その相加平均点をもつて震度とする．この震度はほぼ国際震度階にひとしい．気象庁震度との換算は，一応 I＝2.5, II＝3.5, III＝5 とした．

Table 1. Comparison of intensity scale by Y. Sato with the usual Japanese intensity scale by J.M.A.

| SATO | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J.M.A. | 0 無感 | I 微震 | II 軽震 | III 弱震 | IV 中震 | V 強震 | | | | VI 烈震 | |

**Table 2. Form of questionaire used. (For weak intensity designed by Y. Sato)**

年 月

(観測地： )

(地形・地質： )

| | 事項 | 注意事項 | 記載例 8日 時13 分10 | 記載例 19日 時21 分45 | 報告者：氏名 日 時 分 | 日 時 分 | 日 時 分 | 日 時 分 | 日 時 分 | 日 時 分 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | . | . | . | . | . | . | . | . |
| 1 | 人のかんじ (1) | B. 屋内で静かにしていた人，少数が感ずる | | | | | | | | |
| | | C. 静止している人かなりに感ずる | | C | | | | | | |
| | | D. 屋内の人大部分に感ずる | D | | | | | | | |
| | | D' 屋外にいる人もいくらか感ずる | D' | | | | | | | |
| | | E. 屋内では誰でも感ずる | E | | | | | | | |
| | | E' 屋外でも多数の人が感ずる | | | | | | | | |
| 2 | 眠つていた人 (2) | D. 少数の人目をさます | | | | | | | | |
| | | E. かなりの人が目をさます | | | | | | | | |
| 3 | 人のたいど (3) | D. 少しおどろく | | | | | | | | |
| | | E. かなりおどろく | E | | | | | | | |
| | | E' にげる人も少しある | | | | | | | | |
| 4 | 振子時計 (5) | C. ごく少数がとまる | C | C | | | | | | |
| | | D. 少しはとまるものもある | | | | | | | | |
| | | E. かなりとまる | | | | | | | | |
| 5 | 電燈など (6) | C. ほんの少しゆれる | | C | | | | | | |
| | | D. かなりゆれる | D | | | | | | | |
| | | E. 大きくゆれる | | | | | | | | |
| | | D' 電線がいくらかゆれる | | | | | | | | |
| 6 | 家具 (9) | C. 小さな音をたてる | | | | | | | | |
| | | D. 一寸したおとをたてる | | | | | | | | |
| | | E. かなりの音 | E | | | | | | | |
| 7 | 木造の家 (12) | B. 戸などがかすかに音をたてる | | B | | | | | | |
| | | C. いくらか音をたてる | | | | | | | | |
| | | D. がたがた<br>E. みしみし | D | | | | | | | |
| 8 | 地なり (37) | きこえたか，きこえぬか， | かすかにきこえた | きこえぬ | | | | | | |
| | | 東西南北どちらの方向から | 東北 | | | | | | | |
| | | どんな音か | ごー | | | | | | | |

注意 1. 記載例にならつて地震を感じたたびに注意事項のどのことが起つたかをしらべて，ABC等をかきこむこと.

2. 1ケ月ごとに紙をかえること，1ケ月たたないでいつぱいになつたら次の紙にかくこと.

3. 1ケ月全然地震を感じなかつた場合もこれは大切な証拠ですからその旨明記して報告すること.

4. 感じた人本人のいた所を観測地というのである. その場所の町村名字名を明記すること，ある地震だけいつものところとちがう場所で観測した場合は欄外にわかるように明記して下さい.

5. 午後は 12 時～24 時ですから，まちがえずに書いて下さい.

## 4. 震度調査結果

上記調査表による調査は数十ケ所の県内気象観測所（区内観測所をふくむ）に対しおこなわれた．報告用紙は有感地震がないばあいも毎月提出してもらうことにした．しかし，報告ははじめは 30 くらいあつまつたが，次第に未提出のところができて，1～2 月には20くらいになり，それ以後は数カ所が断続的に報告する程度となつた．以後特別な処置をとらず，一応 2 月までの半年についてのみ整理をおこなつた．

Figs. 4～7 にこの期間に生じたおもな有感地震の震度分布をしめす．無感の観測点としてはその地震の報告された月に調査表を提出しているところだけを有効な無感観測点とみなして白円でしめした．Table 3 にはこれらの地震の中央気象台地震月報および大阪管区気象台地震月報による資料をしめした．震央が中央気象台地震月報と大阪管区気象台地震月報とでことなるものは，前者を $E_2$，後者を $E_1$ として区別した．*P–S* 時間と区内観測所震度は大阪管区気象台地震月報のみに公表されている．

洲本，和歌山，潮岬，尾鷲各測候所および湯浅耐久高校（震研委託石本加速度計設置）における地震計による検測の有無も Fig. 4 に×印でしめしてあるが，これは同一型式の地震計をもちいている測候所でも倍率はちがつており，また雑地動水準も区々であるから，正確な比較をすることはできないが，これら局地地震の現在の地震観測網による観測の状況をしるためにのせた．

これら 24 の地震のうち 8 ケ（Fig. 4 にしめした Nos. 1, 6, 10, 14, 15, 16 と Fig. 7 にしめす 23, 24）は「和歌山附近」，7 ケ（Fig. 5 にしめした Nos. 3, 8, 12, 13, 18, 20 と Fig. 7 の No. 9）は「紀伊水道」，(Fig. 7 にしめす No. 9 は「紀伊水道南部」)，6 ケ（Fig. 6 にしめした Nos. 4, 5, 11, 19, 21, 22）は「和歌山県中部」と発表されており，他に 1 ケづつ，No. 7 (Fig. 7) は「和歌山県北部」，No. 2 (Fig. 7) は「日高川河口附近」，No. 17 (Fig. 7) が「有田川下流域」と発表されている．つぎにこれらの震央を震度分布とくらべて検討してみよう．Nos. 6, 15, 16, 23, 24 の 6 ケは「和歌山附近」でよいが，No. 24 の震央位置は洲本の無感という事実を考慮して数 km ずらせて有感範囲内におくのが妥当とおもわれる．No. 1 の震度分布は No. 2 にちかいので，もし同様とすれば震央を「日高川河口附近」とすることになる．No. 10 は験測は高松，亀山のみであり，明瞭でないが，和歌山，洲本の無感という点から「紀伊水道」の弱震とかんがえられる．No. 14 は震度分より「有布田川下流域」のものと推定したい．

「紀伊水道」とされてるもののうち Nos. 3, 8, 9, 13 の 4 ケは問題がないが，No. 12 は「有田川下流域」，No. 18 は「紀淡海峡」とした方がよいとおもわれる．No. 20 は「和歌山県中部」とされている No. 22 にややちかい震度分布であるが，震源が多少ふかい（地殻下地震）ために不明瞭な震度分布となつていて震央をはつきり推定することはこれからはできにくい．

Nos. 4, 5, 11, 19, 21, 22 の 6 ケは「和歌山県中部」という漠然とした範囲であらわされているので，特に支障はないであろうが，No. 5 の震央位置はあきらかに 10～20 km

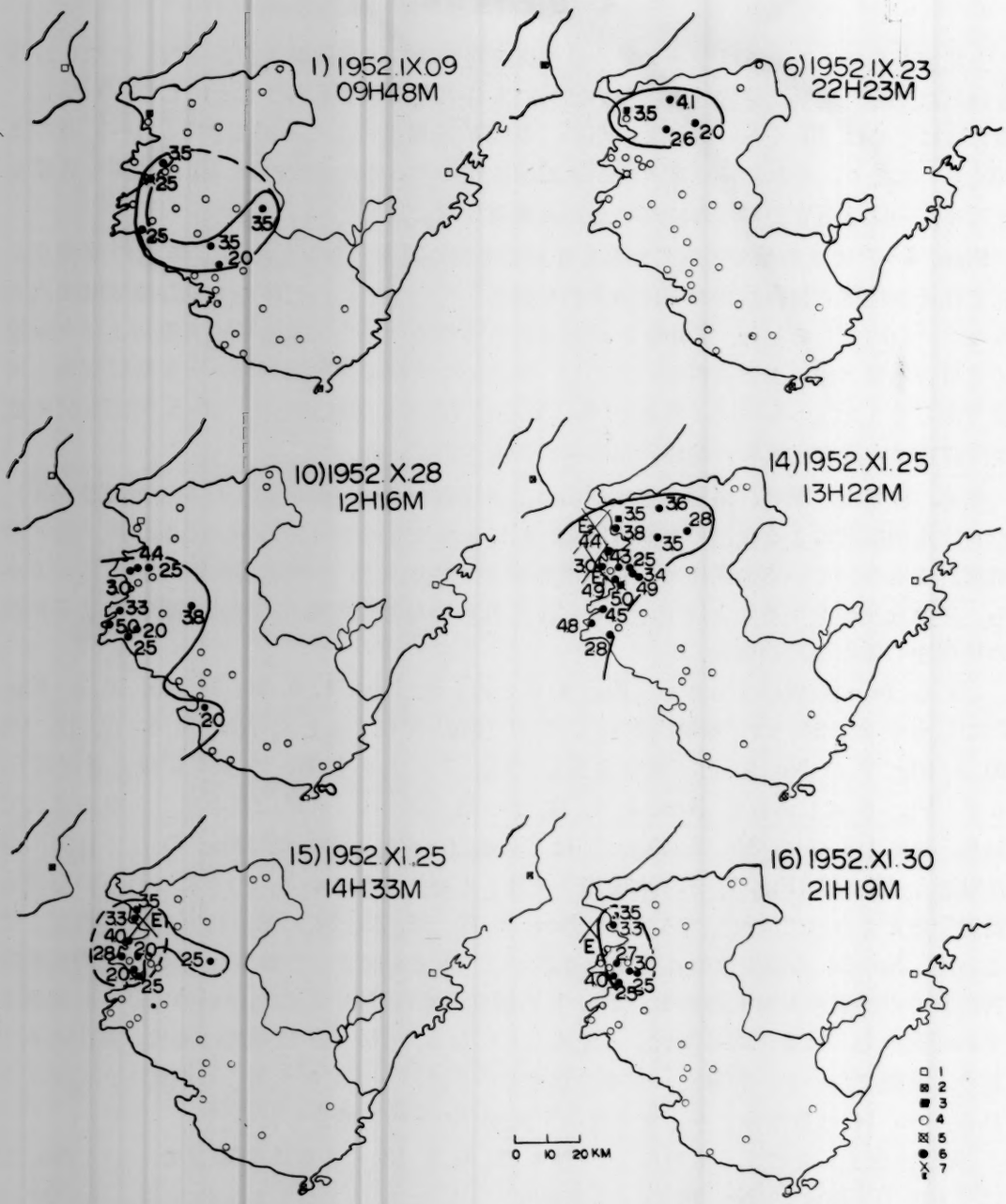


Fig. 4. Intensity distribution of rather strong earthquakes felt in Wakayama Pref. during Sept. 1952~Feb. 1953. Published locations are "Near Wakayama". 1, 2, 3–Weather station. 4, 5, 6–Entrusted substation. 1, 4–Not felt, not recorded. 2,5–Not felt, but recorded. 3, 6–Felt. 7–Published epicenters. ($E_1$: Osaka Distr. Met. Obs., $E_2$: J.M.A.)

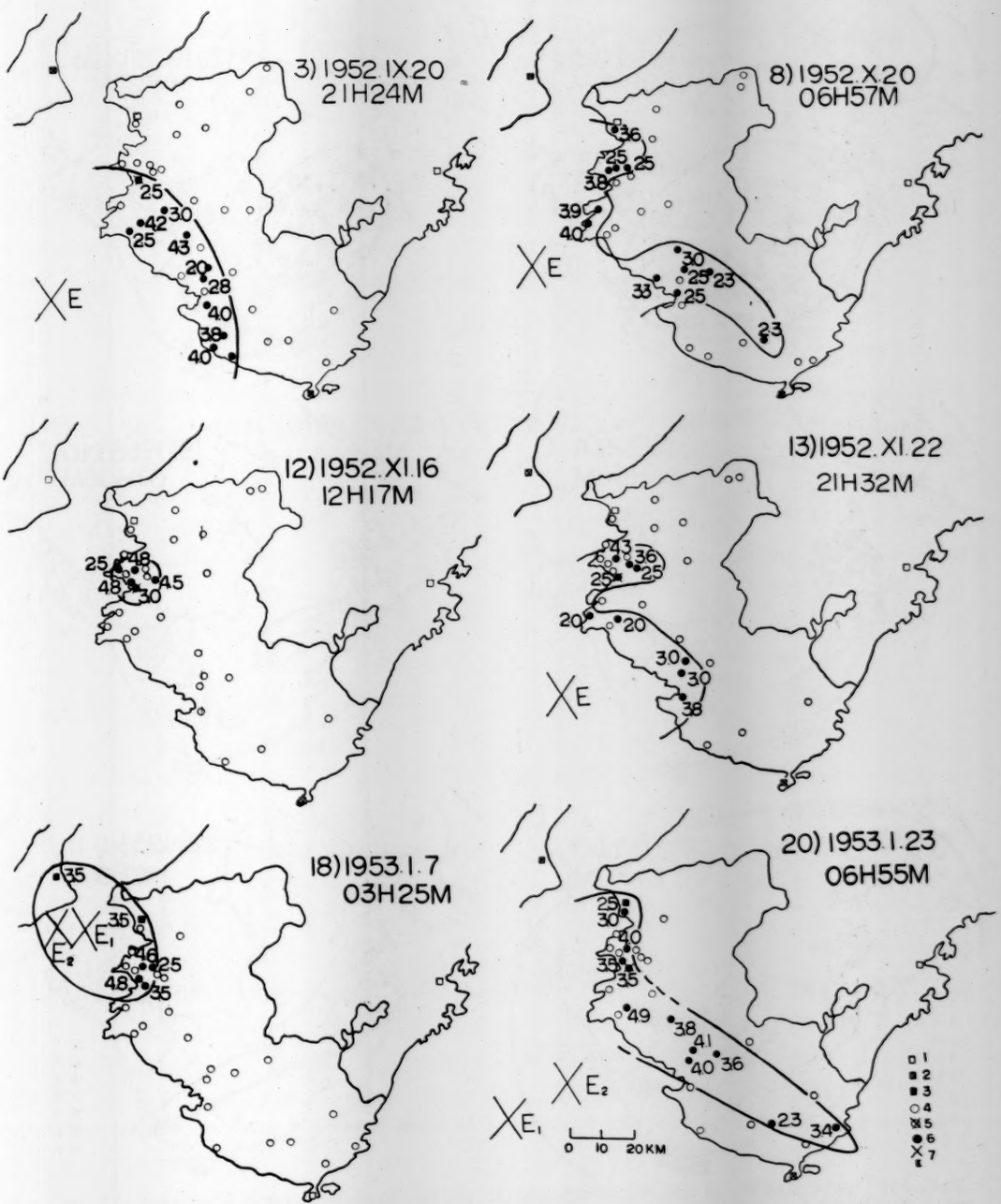


Fig. 5. Intensity distribution of rather strong earthquakes felt in Wakayama Pref. during Sept. 1952～Feb. 1958. Published locations are "Kii Strait". 1-7-Same as in Fig. 4.

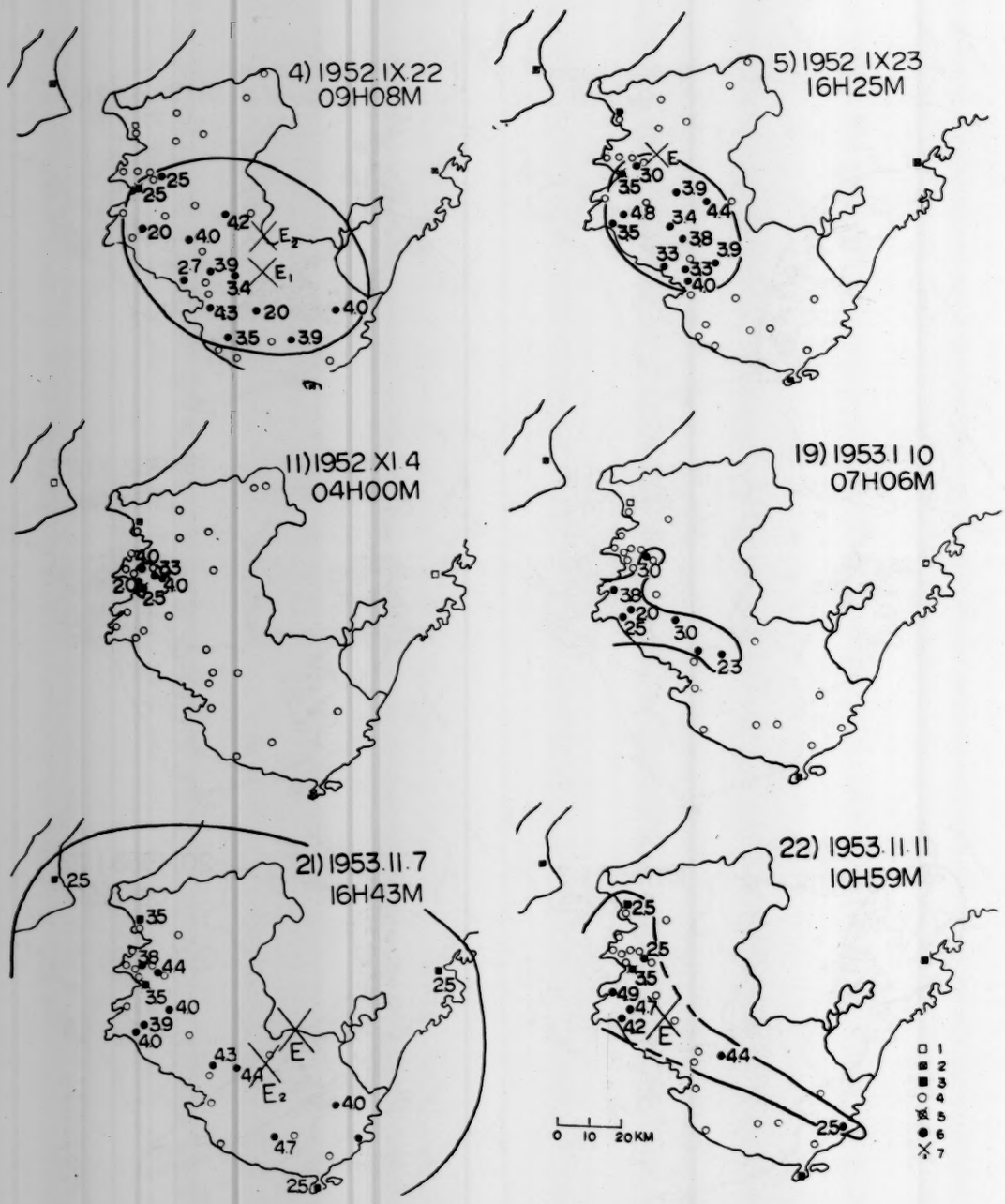


Fig. 6. Intensity distribution of rather strong earthquakes felt in Wakayama Pref. during Sept. 1952～Feb. 1953. Published locations are "Central Part of Wakayama Prefecture".
1-7-Same as in Fig. 4.

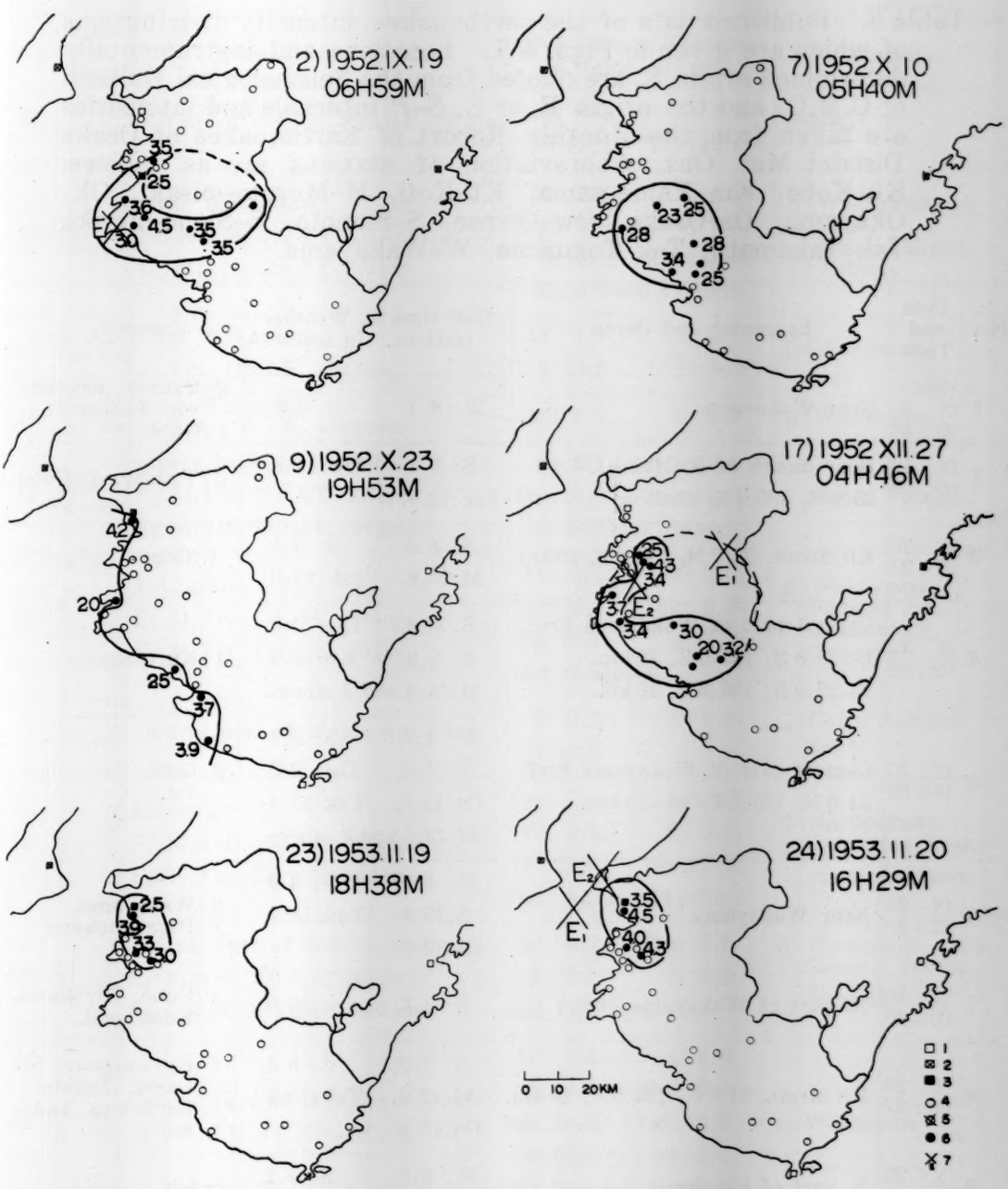


Fig. 7. Intensity distribution of rather strong earthquakes in Wakayama Pref. felt during Sept. 1952～Feb. 1953. Published locations are as follows: No. 2–Near the mouth of R. Hidaka, No. 7–Northern part of Wakayama Prefecture, No. 9–Southern part of Kii Strait, No. 17–Lower basin of R. Arita, Nos. 23,24–Near Wakayama.
1–7–Same as in Fig. 4.

Table 3. Published data of the earthquakes, intensity distributions of which are given in Figs. 4–7. Locations and instrumentally determined origin $E_2$ are quoted from the Seismological Bulletin of C.M.O. and the origin $E_1$ or E, *S–P* intervals and intensities are taken from the Monthly Report of Earthquakes of Osaka District Met. Obs. Abbreviation of stations are as follows: Kb–Kobe, Km–Kame-yama, Kt–Koti, M–Muroto-misaki, Ok–Okayama, Os–Osaka, Ow–Owase, S–Sumoto, S–Siono-misaki, Tak–Takamatu, Tok–Tokusima, W–Wakayama.

| No. | Date and Time | Epicenter and Depth | *S–P* time at Weather stations. (in sec.) | Intensity |
|---|---|---|---|---|
| — | —1952— | | | |
| 1 | IX 9 09 : 48 | Near Wakayama. | W: 6.1, S: 5.8. | II : Ryuzin, Kiyokawa, Tadono.<br>I : Gobo. |
| 2 | IX 19 06 : 59 | Near mouth of R. Hidaka.<br>33.9 N, 135.1 E, shallow. | S: 6.1, Ow:11.8,<br>Tak:12.8. | II : Tadono. I : Gobo. |
| 3 | IX 20 21 : 23 | Kii Strait. 33.7 N, 134.9 E, 10 km. | S: 8.4, Ŝ: 9.4,<br>M:10.6, Tak:12.0. | I : Gobo |
| 4 | IX 22 09 : 08 | Central part of Wakayama Pref.<br>$E_1$:33.8 N, 135.6 E, 20 km.<br>$E_2$:33.9 N, 135.6 E, 10 km. | Ŝ: 6.9, Ow: 7.2<br>S: 9.9, Kb:14.3<br>M:14.4 and 3 others. | I : Kurusugawa |
| 5 | IX 23 16 : 25 | Central part of Wakayama Pref.<br>34.0 N, 135.3 E, 10～20 km. | W: 3.7, S: 5.7<br>Ŝ: 9.0, Ow: 9.7<br>Os:12.0, Tak:13.4<br>M:12.5 and 8 others. | II : Gobo, Kurusugawa. |
| 6 | IX 23 22 : 23 | Near Wakayama. | W: 1.1, S: 3.9<br>Ŝ:15.8, Tak:14.7<br>Os:19.8 | II : Wakayama,<br>I : Higasi-nokami |
| 7 | X 10 05 : 40 | N. part of Wakayama Pref. | S: 5.8, Ow:10.0 | I : Gobo, Kiyokawa, Kawakami. |
| 8 | X 20 06 : 57 | Kii strait. 33.8 N, 134.9 E, 20 km. | S: 7.0, Ŝ: 9.4,<br>M:10.0, Tak:10.9<br>Os:19.3. | I : Kurusugawa, Ŝitikwa, Tanabe, Kiyokawa, Tadono. |
| 9 | X 23 10 : 53 | S. part of Kii Strait. | W: 6.5, S: 7.2,<br>Kt:11.2, Ok:21.6 | unfelt |
| 10 | X 28 12 : 16 | Near Wakayama. | Tak:11.7, Km:20.7 | I : Tadono, Gobo. |
| 11 | XI 4 04 : 00 | Central part of Wakayama Pref. | W: 3.7, Ŝ: 8.1 | unfelt |
| 12 | XI 16 12 : 17 | Kii Strait. | Ŝ: 9.8, Tak:11.0 | unfelt |

(to be continued)

(continued)

| No. | Date and Time | Epicenter and Depth | *S–P* time at Weather stations. (in sec) | Intensity |
|---|---|---|---|---|
| 13 | XI 22<br>21 : 32 | Kii strait. 33.7 N, 135.0 E, 20 km. | Ŝ: 8.0, S: 8.7,<br>M:10.9, Tak:12.2 | unfelt |
| 14 | XI 25<br>13 : 22 | Near Wakayama.<br>$E_1$;34.1 N, 135.1 E, 20 km.<br>$E_2$:34.2 N, 135.1 E, 20 km. | W: 2.2, S: 4.2,<br>Tok: 6.5, Os: 9.3,<br>Ŝ:11.7, Tak:15.5,<br>M:16.0 and 8 others. | II :Wakayama, Gobo, Higasi-nokami,<br>I :Tadono. |
| 15 | XI 25<br>14 : 33 | Near Wakayama.<br>34.2 N, 135.2 E, shallow. | W: 1.8, S: 5.1,<br>Trk:13.9, Ŝ: 2.3? | II :Wakayama. |
| 16 | XI 30<br>21 : 19 | Near Wakayama<br>34.2 N, 135.1 E, shallow. | W: 1.7, S: 4.3 | II :Wakayama. |
| 17 | XII 27<br>04 : 46 | Lower basin of R. Arita<br>$E_1$:34.1 N, 135.5 E, 10 km.<br>$E_2$:34.0 N, 135.2 E, 40 km. | S: 6.8, Ŝ:10.1<br>Ow:10.8, Tak:11.9<br>M:13.9 and 7 others | I :Gobo, Tadono. |
| — | 1953— | | | |
| 18 | I 7<br>03 : 25 | Kii Strait.<br>$E_1$:34.2 N, 135.0 E, 20 km.<br>$E_2$:34.2 N, 134.9 E, 10 km. | W: 3.6, S: 3.3,<br>Tok: 6.0, Tak: 9.9<br>Ow:13.7, S:13.4<br>and 15 others. | II :Wakayama, Sumoti.<br>I :Tokusima, Tadono. |
| 19 | I 10<br>07 : 06 | Central part of Wakayama Pref. | Ŝ: 9.8, S: 1.0?<br>M:12.5 | I :Gobo, Kurusu gawa. |
| 20 | I 23<br>06 : 55 | Kii Strait.<br>$E_1$:33.6 N, 134.8 E, 40 km.<br>$E_2$:33.7 N, 135.0 E, 40 km. | Tok: 7.6, Ŝ:10.2<br>W: 9.1, S: 9.3,<br>M:10.6, Ow:12.9,<br>Tak: 8.3 and 14 others. | II :Kurusugawa,<br>I :Tokusima, Wakayama, Ŝitikawa. |
| 21 | II 7<br>16 : 43 | Central part of Wakayama Pref.<br>$E_1$:33.9 N, 135.7 E, 20 km.<br>$E_2$:33.8 N, 135.6 E, shallow. | W: 6.2, Ow: 5.8<br>S: 9.5, Ŝ: 6.3<br>and 12 others. | II :Wakayama.<br>I :Sumoto, Owase, Ŝiono-misaki |
| 22 | II 11<br>10 : 59 | Central part of Wakayama Pref.<br>33.9 N, 135.3 E, 10～20 km. | W: 4.6, S: 6.6<br>Ŝ: 8.5, Ow: 9.7<br>Tok:10.8, Tak:10.6<br>Os:13.6, M:17.2<br>Kt:16.0 and 7 others. | I :Wakayama |
| 23 | II 19<br>18 : 38 | Near Wakayama. | W: 1.3, S: 3.9,<br>Ŝ:13.7 | I :Wakayama |
| 24 | II 20<br>16 : 29 | Near Wakayama.<br>$E_1$:34.2 N, 135.0 E.<br>$E_2$:34.3 N, 135.1 E, very shallow. | W: 1.8, S: 2.6<br>Tak:11.7, Os:13.2<br>Ŝ:10.8 and 5 others. | II :Wakayama |

南方にずらすべきであろうし，No. 11 は「有田川下流域」と指定できよう．また No. 7 は「和歌山県北部」でなく「中部」である(誤植?)．No. 17 は「紀伊水道」というべきものかもしれない．

Nos. 11, 12, 13 の3地震は地震月報でも無感地震とされているものであり，区内観測所の報告がなければ，そのほか Nos. 1, 2, 3, 4, 5, 7, 8, 10, 17, 19 の 10 地震もすべて無感地震とされたはずである．つまりこれらの局地地震はこの時期の有感地震としてはややつよいものであるが，それでもその 1/2 は測候所観測のみでは有感であることが認識されないことになるのである．

なおこれらの震度分布において地盤の影響もかなりあらわれているようであるが，今回はこれについてくわしく考察することは省略した．

## 5. 震度調査結果 2

この調査で半年間にみとめられた有感地震は 423 であり，そのうち1点のみで有感のもの 276，2点で有感のもの 83，等 Table 4 にしめすような結果がえられており，前節でとりあつかつた地震よりさらにちいさい局地地震が多数有感地震としてみとめられていることがわかる．これらのうち，有感報告が隣接している観測点からもあつたものと，1点のみで有感になつているものは一応震央をその観測点附近と推定できるわけであるが，とびはなれた観測点で有感となつているものもまれにあり，これは震動がよわいための観測の誤差によるとおもわれるが，深発地震のための震度分布異常にもとづくばあいもあるようである．

区内観測所の報告について 1952～1958 について1点（近接点は1点で代表）のみの有感から小局地地震の分布を推定したのと同様なことをおこなつたが，観測点分布が一様でないことと，同一観測点で一貫して報告のある点がすくないので通算ができず，適当な資料とおもえないので掲載をさしひかえた．

Fig. 8 は毎月の各点の有感地震回数をしめした分布図である．この期間の各月間に顕著な活動の移動はみられない．

この調査は不完全なものであつたが，これによつて短期間に区内観測所の長期にわたる報告を整理した結果によるとほぼ同様の程度に和歌山県下の地震活動状況の概要をしることができた．

## 6. 震度報告の重要性

Fig. 3 にしめした器械観測による震央は ±0.1°（約 ±10 km）でしめされているがこれらはすべて相当つよい地震で，かなり多数の測候所で計測されたものである．一方 Fig. 2 でしめしたような活動分布をしめす地震は，区内観測所1点のみで有感であつた局地的なよわい地震である．区内観測所の間隔はやはりほぼ 20 km 程度であるから，このような有感報告で，震央位置を ±10 km の程度におさえることができていることになる．

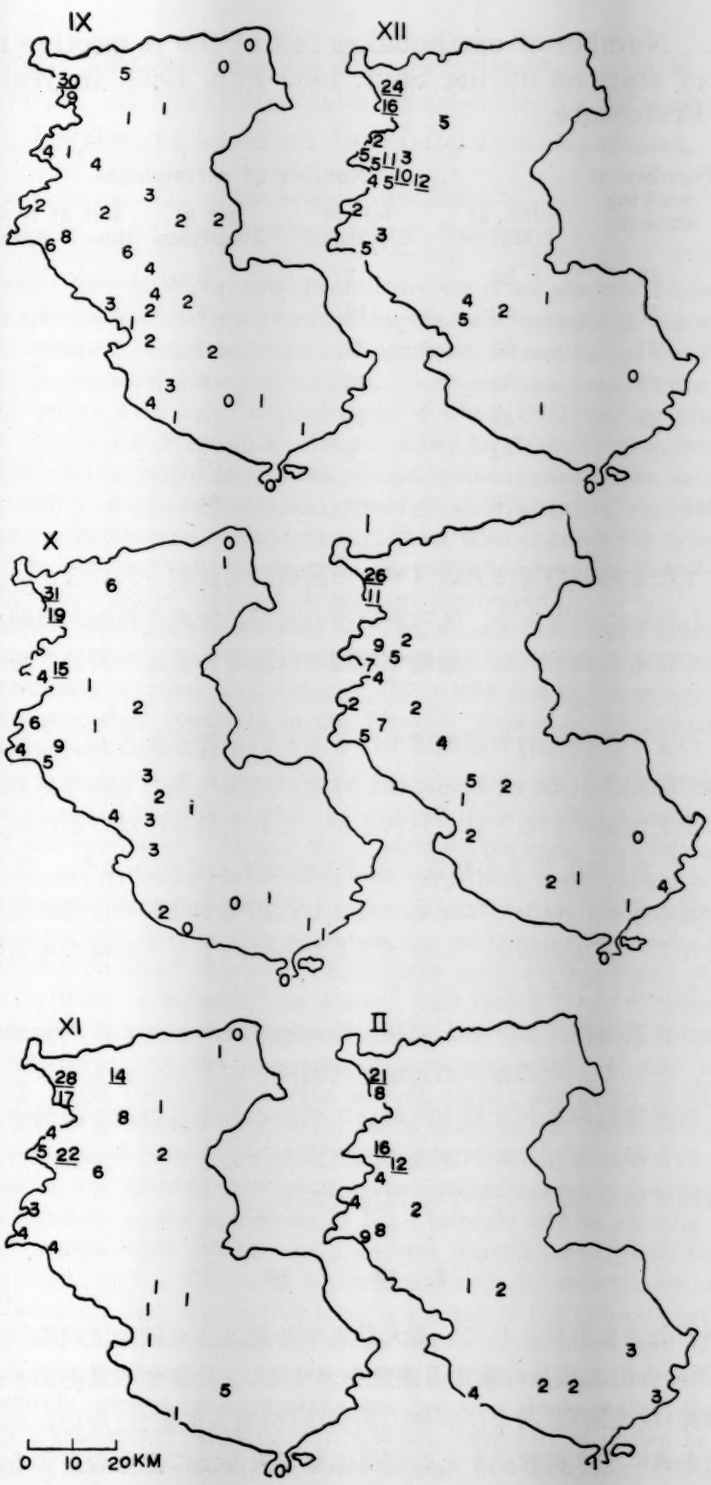


Fig. 8. Monthly numbers of earthquakes felt at the intensity stations in Wakayama Prefecture obtained by the questionaire survey during Sept. 1952～Feb. 1953.

Table 4. Number of earthquakes felt at the respective number of stations during Sept. 1952–Feb. 1953. in Wakayama Prefecture.

| Period | Number of working stations | Number of earthquakes. | | | | |
|---|---|---|---|---|---|---|
| | | felt at 1 station | felt at 2 stations | felt at 3 stations | felt at more than 3 stations | Total |
| 1952 IX | 33 | 34 | 7 | 5 | 7 | 53 |
| 1952 X | 27 | 40 | 14 | 7 | 6 | 67 |
| 1952 XI | 22 | 62 | 29 | 3 | 8 | 102 |
| 1952 XII | 21 | 53 | 15 | 6 | 5 | 79 |
| 1953 I | 22 | 43 | 10 | 6 | 3 | 62 |
| 1953 II | 17 | 44 | 8 | 4 | 4 | 60 |
| Total | | 276 | 83 | 31 | 33 | 423 |

しかも，このようなよわい地震は大体 1～2 の測候所で験測されればよい方で，まつたくどこでも験測されないこともある．区内観測所の有感，無感の観測が信頼されるならば，地震計観測だけではもとめられない局地小地震の分布をあきらかにしうるものであることがわかる．

もちろん，このような局地的有感地震中にもふかい地震があるが，これは大抵いくつかの遠隔の測候所で験測される．それらのほかはすべて極浅発のものであり，その分布は地殻表層の地質構造と関係があるとおもわれるが，これを詳細に論ずるには，地質構造の単元以下，たとえば ±1 km 以下の精度で震源を決定する必要があり，これには当然より精密な観測を必要とする．しかしながら，そうした局地小地震の活動状況の分布の概略をひろい範囲にわたり一様な信頼度でしらべうるならば，より大規模な地質構造と関連して興味ある推論をおこないうるものとおもう．

大阪管区気象台地震月報におけると同様に他の地区においても区内観測所の震度報告が公表されること，そして，その報告の密度と信頼性とがさらに向上することを切に期待するものである．有感地震のまれな地方において信頼のおける報告を確保することはことに非常に困難であろうが，現在程度の密度の区内観測所でもすべてが信頼できるならば，すばらしい局地地震活動分布図がえられるはずである．

## 7. 謝　　辞

貴重なる資料の公表を継続されている大谷東平台長以下大阪管区気象台および管下各地方気象台，測候所の各位に深甚の敬意と謝意を表する．また著者の震度調査に協力をえた和歌山県企画広報課（現企画室）および和歌山測候所（現地方気象台）のかたがたに感謝する．おわりに震度調査表につき御教示をえた同僚佐藤泰夫博士に謝意を表する．

# 37. *Local Earthquakes in Kii Peninsula, Central Japan. Part II. A Brief Review of Seismicity in Wakayama Prefecture based on Intensity Investigations.*

By Setumi MIYAMURA,
Earthquake Research Institute.

In the central part of Wakayama Prefecture we often observe an earthquake felt, seismic waves from which are not recorded by the seismographs at two routine seismological stations situated on the northern and southern extremities of the Prefecture, i.e. Wakayama and Sionomisaki Weather Stations. Such earthquakes are either very shallow local shocks or rather deep small earthquakes, of which the latter are often recorded at a few stations outside the Prefecture. On the other hand, the former, being recorded at no seismological station, might have been missed from our earthquake catalogue, if they were not reported from the substations entrusted with intensity report by J.M.A. at many places in the Prefecture. Consequently, if we wish to know the seismicity of such local earthquakes, we must not only depend upon published seismometrical data, but also consult the intensity reports obtained throughout the region.

Those intensity substations entrusted by J.M.A. are distributed throughout Japan, but they are not necessarily working well. However, in Wakayama Pref. about 20 of them were fortunately working well through 1952～1958 and the intensity reports from them have been published regularly in the Monthly Report of Earthquakes by Osaka District Meteorological Observatory.

After those intensity data we calculated the mean annual numbers of earthquakes felt at various plases in the Prefecture and showed them in Fig. 1, indicating the general feature of the seismicity. Among those earthquakes some were felt only at a single station and it means that such earthquakes are very local ones, the epicenters of which must lie in a polygon, its sides being the perpendicularly bisecting straight lines of the segments connecting the station with neighbouring stations, as shown in Fig. 2. They are either very shallow small shocks or rather deep small earthquakes. And only a few seismographic stations, occasionally no station, can record them. Consequently their epicenters cannot be determined seismometrically. But the assumed epicentral polygon stated above corresponds to the epicenter of accuracy within 10 odd kms. Annual numbers of such single station felt shocks at each station are given in Fig. 2 and indicate the seismicity of such very small local earthquakes in the Prefecture in 1952～1958.

In order to compare the seismicity of such very local felt shocks with that of rather larger earthquakes, the epicenters of which were determined seismometrically, we show in Fig. 3 total numbers of the epicenters in Kii Peninsula and its vicinity at respective positions of 0.1 degree mesh points. As a general feature there are no remarkable difference among Figs. 1～3. The most active seismicity is concentrated in the neighbourhood of Wakayama and next active zone is limited in the littoral part of Kii Strait around Tadono and Gobo, including the lower basins of R. Arita and R. Hidaka. In the northeastern and southeastern corners of the Prefecture, i.e. Ito and Higasi-muro counties respectively, almost no earthquake was felt at a single station there as seen in Fig. 2 and only a few widely shaking earthquakes were felt as shown in Fig. 1. No larger earthquakes occurred in the two zones as seen in Fig. 3, too. Thus we conclude that they are the most aseismic parts of the Prefecture, though the geological situations are far different in both.

On the other hand, second class local seismic centers are also inferred in the middle course of R. Hidaka around Kawakami and in the basins of R. Tomita and R. Hiki around Kurusugawa and Itikano-Hiki respectively as shown in Figs. 1～2. Fig. 3, however, illustrates another concentration of epicenters in the upper reaches of R. Hidaka around Ryuzin instead around Kurusugawa.

During Sept. 1952～Feb. 1953 the author tried to collect information on perceptible earthquakes in Wakayama Prefecture by means of questionaires, designed by Y. SATO for the survey of low intensity earthquakes based on 12 degrees international scales, form of which is shown in Table 2. Correspondence with this intensity scale and that of J.M.A. is given in Table 1. The questionaires were sent to several tens of public schools and administrative offices throughout the Prefecture and every month they were requested to be sent back, even when no earthquake was felt. But we could get back only about 20～30 questionaires.

Intensity distributions of 24 large earthquakes felt during the survey period are illustrated in Figs. 4～7, classified in their published locations of the origins, tabulated in Table 3. In the table seismometrical data and intensity reports are also given after the Monthly Report of Earthquakes of Osaka District Meteorological Observatory.

Among the earthquakes published as those occurring "near Wakayama", the epicenter of No. 24 should be shifted further south, at least several kilometers, considering the fact that the shock was not felt at Sumoto Weather Station. Intensity distribution of No. 1. seems to be similar to that of No. 2 and might have occurred "near the mouth of R. Hidaka" as No. 2. No. 10 may probably have originated in "Kii Strait" instead "near Wakayama". No. 14 is said to belong to the earthquake in "lower basin of R. Arita" instead of that occurring "near Wakayama".

Among the earthquakes published as those occurring in "Kii Strait", No. 12 and No. 18 should be corrected to belong to those originating in "lower basin of R. Arita" and in "Ki-tan Strait" respectively. Intensity distribution of the earthquake No. 20 resembles somewhat to that of No. 22, which was published as occurring in "central part of Wakayama Prefecture", but, perhaps, owing to its subcrustal nature, we cannot easily fix the epicenter by the intensity distribution.

Earthquakes shown in Fig. 6 are those published as occurring "in the central part of Wakayama Prefecture", and among them the epicenter of No. 5 should be shifted more than 10 km to the south. No. 11 should probably belong to that occurring "in the lower basin of R. Arita". Published location of the earthquake No. 7 may be misprinted and should be read "in the central part of Wakayama Prefecture" instead of "in the northern part of the Prefecture". Earthquakes of Nos. 11, 12, 13 were classified in the Seismological Bulletin as unfelt. Nos. 1～5, 7, 10, 17, 19 might have been also classified as unfelt, if there were not the intensity reports from the entrusted substations. Consequently though these 24 earthquakes are not very small ones among the local felt shocks in the region, about one half of them might have not been recognized as felt earthquakes and their epicentral locations might have been also misinterpreted.

Monthly numbers of felt shocks reported during our questionaire survey are given in Table 4 and Fig. 8, which do not show any remarkable change of seismicity in the period. General feature of the seismicity in the Prefecture is similar to those discussed in the previous section based on the J.M.A. data for the longer period.

In conclusion the author emphasizes the need to strengthen and to secure the intensity report of entrusted substation all over the country, in order to get the correct picture of seismicity, especially that of the very shallow local earthquakes.

地震研究所彙報
第37号 (1959) 609-635頁

# 38. 紀伊半島の局地地震 (第3報)

## ——和歌山附近における臨時地震観測網——

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(昭和 28 年4月 21 日，29 年3月 23 日，34 年9月 22 日発表——
昭和 34 年9月 29 日受理)

すでに報告した高感度地震計による偵察観測[1]と人体感覚にもとづく震度調査[2]とにより，紀伊半島の局地地震の現在の活動中心は和歌山県北西部の和歌山附近にあり，その深度はきわめてあさいものであるということが推定された．このような極浅発局地地震と地質構造との関係をしらべることは興味ある問題であるが，それにはまづ震源位置の精密な決定が必要である．そのために 1952 年秋以降 1956 年春まで4回にわたり，この地域に臨時地震観測網をもうけて，精密な刻時方式による観測を実施した．基本地震計としては石本式加速度計3成分をもちい，記録紙速度約 4 mm/s, 1952 年には JJY 無線報時を，1953—1956 年には LTC[3]方式で基地標準時計の分秒刻時をそれぞれ記象上に直接記入，±1/50 秒の刻時精度をえた．また電子地震計による自然地震の高感度連続観測，LTS[4], RTS[5] による無人観測の実施等あたらしい地震観測法を開発し，その実地試験をおこなつた．ここにはこれらの臨時観測網の概要と観測資料の一部をのべる．観測結果の詳細の解析は第4報以下に報告する予定である．

### 1. 序　言

第1報[1]で検討したように，今回の和歌山地方の頻発地震群のもつとも活溌な中心地域は和歌山県中部海岸に位置する御坊町より北方にあることはたしかであり，種々の資料よりみて，和歌山市と湯浅町とのあいだの海草郡および有田郡の海岸地方にかぎられるものと推定された．これは地質からみると，長瀞変成帯（従来の三波川系，御鉾系）とその南方に接する非変成秩父累帯古生層乃至中生層のしめるところで，中央構造帯と仏像・糸川構造線にはさまれる地域である．

もちろん，この地域外にも紀伊半島の局地地震活動がないわけではない[2]．特に紀伊山

1) S. MIYAMURA, "Local Earthquakes in Kii Peninsula, Central Japan. Part I. Reconnaissance Observations of Minor Shocks at Gobo, Wakayama Prefecture," *Bull. Earthq. Res. Inst.*, **37** (1959), 347–358.

2) S. MIYAMURA, "Local Earthquakes in Kii Peninsula, Central Japan. Part II. A Brief Review of Seismicity in Wakayama Prefecture based on Intensity Investigation," *Bull. Earthq. Res. Inst.*, **37** (1959), 593–608.

地内部の状況は,観測においてもなお不充分のきらいがあるので,研究がすすむにつれて,このほかにも活動中心のみいだされる可能性もあるが,一応,もつともいちぢるしい地震地域として,上記の地域をとりあげ,その地震状況の研究をおこなうことにした.

基本観測点の地震計としては石本式加速度計 (IA) をもちい,できるだけ記録紙速度をはやくして,同一標準時計による分秒刻時を各点の記象上に直接記入させ[3],現在の常時観測はもちろん,従来の余震観測等のいかなるばあいよりも精度のたかい観測をおこなうようにつとめた.観測は臨時的に 1952～1954 年毎秋および 1956 年春約 1～2 ヶ月程度,Table 1 のごとき計画で実施した.

Table 1. Schedules of the temporary seismological network operations in the neighbourhood of Wakayama, 1952～1956. IA—Ishimoto accelerograph. ES—Electronic seismograph. JJY—Standard radio time signal, 4 Mc/s.

| No. | Year | Date | Number of | | Time service | Number of | |
|---|---|---|---|---|---|---|---|
| | | | IA stations | ES stations | | LTS stations | RTS stations |
| 1 | 1952 | X 20－XII 20 | 5 | 0 | JJY | 0 | 0 |
| 2 | 1953 | X 20－XII 20 | 6 | 1 | LTC | 1 | 0 |
| 3 | 1954 | XI 10－XII 20 | 6 | 1 | LTC | 2 | 1 |
| 4 | 1956 | III 27－IV 30 | 6 | 2 | LTC | 2 | 3 |

また,精密観測としての必然的要求と,1954 年ごろよりの地震活動度の若干の低下に応ずる対策とから,電子地震計による高感度観測の研究をすすめ,特に有線搬送遠隔記録地震計LTS[4] および無線遠隔記録地震計 RTS[5] による無人観測法を開発,その実地試験をおこなつた.

以下各回の観測網の状況,観測方法,使用計器,観測結果の概要等につきのべる.

## 2. 観測網の概要

各年度における臨時地震観測網の概要として,Table 2 には観測点名称,計器設置場所,その位置(行政区域),観測担当者とその所属機関,設置した主要計器,観測実施期間等を

3) S. MIYAMURA and M. TSUJIURA, "Line Carrier Telerecording Chronograph (LTC) for Local Seismological Network," *Bull. Earthq. Res. Inst.*, **33** (1955), 702–713.

4) S. MIYAMURA and H. MATUMOTO, "Line Carrier Telerecording Seismograph (LTS)," *Bull. Earthq. Res. Inst.*, **33** (1955), 715–724.

5) S. MIYAMURA and M. TSUJIURA, "A VHF Radio Telerecording Seismograph (RTS)," *Bull. Earthq. Res. Inst.*, **33** (1955), 725–731.

S. MIYAMURA and M. TSUJIURA, "UHF Multi-channel Radio Telerecording Seismograph. Part I," *Bull. Earthq. Res. Inst.*, **35** (1957), 381–394.

M. TSUJIURA and S. MIYAMURA, "UHF Multi-channel Radio Telerecording Seismograph. Part II," *Bull. Earthq. Res. Inst.*, **37** (1959), 193–206.

Table 2. Items of the temporary seismological observations in the neighbourhood of Wakayama, 1952～1956.

| 年度 番号 Year, Number | 名称(略号) Name (Abbre-viation) | 観測場所 Place | 位置 Location | 観測者(所属) Observer (Organization) | 主要計器 Instruments | 観測期間 Obs. Period |
|---|---|---|---|---|---|---|
| 1952 1 | 中松江 (NM) | 関西電力松江営業店 | 和歌山市中松江 | 松本英照(震研) | | X 24–XII 15 |
| 2 | 動木 (T) | 関西電力野上変電所 | 海草郡東野上町 | 堀実(震研) | 石本式加速度計（3成分） | X 22–XII 15 |
| 3 | 海南 (K) | 関西電力海南変電所 | 海南市筑地 | 今村久（海南二中） | 短波時報受信機 | X 25–XII 15 |
| 4 | 箕島 (M) | 関西電力箕島変電所 | 有田郡箕島町 | 辻浦賢(震研) | | X 23–XII 15 |
| 5 | 広 (H) | 関西電力広変電所 | 有田郡広町 | 新屋兼次郎（耐久高校） | | X 22–XII 15 |
| 1953 1 | 羅漢寺 (R) | 五百羅漢寺庫裏 | 和歌山市和歌浦口 | 今村久(海南二中) | | X 24–XII 20 |
| 2 | 琴浦 ($KO_1$) | 関西電力琴浦発電所社宅 | 和歌山市毛見 | 松本英照(震研) | | X 27–XII 20 |
| 3 | 動木 (T) | 関西電力野上変電所 | 海草郡東野上町 | 新谷垣内正巳（大成高校） | 石本式加速度計（3成分） | X 25–XII 20 |
| 4 | 海南高 (KA) | 県立海南高等学校 | 海南市大野中 | 西口憲章（海南高校） | LTC 受信機 | X 25–XII 20 |
| 5 | 箕島 (M) | 関西電力箕島変電所 | 有田郡箕島町 | 堀実(震研) | | X 23–XII 20 |
| 6 | 湯浅 (Y) | 県立耐久高等学校 | 有田郡湯浅町 | 新屋兼次郎（耐久高校） | | X 23–XII 20 |
| 7 | 海南 (K) | 関西電力海南変電所 | 海南市筑地 | 辻浦賢(震研) | LTC 送信機 LTS 受信機 | X 27–XII 19 |
| 8 | 大崎 (O) | 升本氏邸内 | 海草郡大崎町加茂郷 | 無人 | LTS 送信機 | 実験のみ |
| 1954 1 | 星林 (SR) | 県立星林高等学校 | 和歌山市西浜 | 小川恵三（星林高校） | 石本式加速度計（3成分） | XI 12–XII 20 |
| 2 | 琴浦 ($KO_2$) | 関西電力琴浦発電所隣接地 | 和歌山市毛見 | 松本英照(震研) | 同上および電子地震計, | XI 10–XII 20 |
| 3 | 海南高 (KA) | 県立海南高等学校 | 海南市大野中 | 西口憲章（海南高校） | LTS, RTS, LTC 受信機 | XI 7–XII 17 |
| 4 | 大成 (TA) | 県立大成高等学校 | 海草郡東野上町 | 新谷垣内正巳（大成高校） | 石本式加速度計（3成分） | XI 6–XII 14 |
| 5 | 箕島 (M) | 関西電力箕島変電所 | 有田郡箕島町 | 田中実蔵（箕島中学） | LTC 受信機 | XI 5–XII 20 |
| 6 | 湯浅 (Y) | 県立耐久高等学校 | 有田郡湯浅町 | 新屋兼次郎（耐久高校） | | XI 5–XII 20 |
| 7 | 海南 (K) | 関西電力海南変電所 | 海南市筑地 | 堀実，辻浦賢（震研） | LTC 送信機 | |
| 8 | 三田 (S) | 関西電力カマ山散宿所 | 和歌山市三田 | 無人 | LTS 送信機 | XI 14–XII 20 |
| 9 | 出島 (D) | 県漁港修築工事々務所 | 和歌山市和歌浦 | 無人 | RTS 送信機 | XI 14–XII 19 |
| 1956 1 | 新高町 (NI) | 小川氏邸内 | 和歌山市新高町 | 小川恵三（星林高校） | 石本式加速度計（3成分） | III 20–IV 29 |
| 2 | 琴浦 ($KO_3$) | 関西電力琴浦発電所事務室 | 和歌山市毛見 | 松本英照(震研) | 同上および電子地震計 | III 30–IV 29 |
| 3 | 海南高 (KA) | 県立海南高等学校 | 海南市大野中 | 西口憲章（海南高校） | LTC 受信機 | III 17–IV 29 |
| 4 | 大成 (TA) | 県立大成高等学校 | 海草郡東野上町 | 新谷垣内正巳（大成高校） | 石本式加速度計（3成分） | III 18–IV 28 |
| 5 | 箕島 (M) | 関西電力箕島変電所 | 有田郡箕島町 | 田中実蔵（箕島中学） | LTC 受信機 | III 20–IV 28 |
| 6 | 湯浅 (Y) | 県立耐久高等学校 | 有田郡湯浅町 | 新屋兼次郎（耐久高校） | | III 17–IV 29 |

| 年度番号 Year, Number | 名称(略号) Name (Abbreviation) | 観測場所 Place | 位置 Location | 観測者(所属) Observer (Organization) | 主要計器 Instruments | 観測期間 Obs. Period |
|---|---|---|---|---|---|---|
| 8 | 海南 (K) | 関西電力海南変電所 | 海南市筑地 | 堀実，辻浦賢 (震研) | LTC 送信機, LTS, RTS 受信機, 電子地震計 | III 30–IV 29 |
| 9 | 伊太祈曾 ($L_2$) | 柳野氏邸 | 海草郡山東村 | 無人 | LTS 送信機 | III 28–IV 29 |
| 10 | 金屋 ($L_1$) | 関西電力金屋変電所 | 有田郡鳥屋城町 | 無人 | | III 27–IV 29 |
| 11 | 東燃 ($R_3$) | 東亜燃料下津港桟橋 | 海草郡下津町 | 無人 | RTS 送信機 | IV 10–IV 30 |
| 12 | 鉢巻山 ($R_1$) | 鉢巻山山頂 | 海草郡加太町 | 無人 | | IV 20–IV 29 |
| 13 | 動木 ($R_2$) | 関西電力野上変電所 | 海草郡東野上町 | 無人 | | IV 20–IV 29 |

Table 3. Coordinates and geology of the stations. Group I were equipped with Ishimoto accelerographs and group II were equipped with electronic seismographs. Coordinate origin is primary triangulation point at Kuro-sima. $\varphi = 34°00'.8\,\mathrm{N}$, $\lambda = 135°05'.6\,\mathrm{E}$, $h = 121.6\,\mathrm{m}$ and $+x$ and $+y$ being taken to the north and east respectively.

| No. | | Name | Abbr. | Year | Coordinates $x$ km | $y$ km | $z$ km | Geology of foundation |
|---|---|---|---|---|---|---|---|---|
| I. | 1 | Nakamatue | NM | 52 | 27.24 | 3.92 | 0 | Alluvium (Sand) |
| | 2 | Rakanzi | R | 53 | 21.29 | 7.15 | 0 | Thin alluvium on paleoz. cryst. schist |
| | 3 | Seirin | SR | 54 | 21.50 | 6.64 | 0 | Alluvium (Sand) |
| | 4 | Niitaka-mati | NI | 56 | 21.91 | 7.06 | 0 | |
| | 5 | Kotono-ura 1 | $KO_1$ | 53 | 17.07 | 8.82 | 0 | Very thin alluvium on paleoz. cryst. schist |
| | 6 | Kotono-ura 2 | $KO_2$ | 54 | 16.99 | 8.60 | 0 | |
| | 7 | Kotono-ura 3 | $KO_3$ | 56 | 17.07 | 8.82 | 0 | |
| | 8 | Kainan | K | 52 | 16.38 | 10.44 | 0 | Alluvium |
| | 9 | Kainan Kōkō | KA | 53, 54, 56 | 16.57 | 12.46 | 0 | Thin alluvium on paleoz. cryst. schist |
| | 10 | Todoroki | T | 52, 53, | 17.72 | 19.63 | 0 | Paleoz. cryst. schist |
| | 11 | Taisei Kōkō | TA | 54, 56 | 17.42 | 19.62 | 0 | |
| | 12 | Minosima | M | 52, 53, 54, 56 | 9.24 | 2.27 | 0 | Very thin alluvium on paleoz.cryst. schist |
| | 13 | Taikyu Kōkō | Y | 53, 54, 56 | 3.42 | 8.23 | 0 | Thin alluvium on mesoz. basement |
| | 14 | Hiro | H | 52 | 1.67 | 7.68 | 0 | |
| II. | 15 | Kainan | $K^E$ | 53, 54, 56 | 16.38 | 10.46 | 0 | Alluvium |
| | 16 | Kotono-ura | $KO_1{}^E$ | 54 | 17.03 | 8.64 | 0 | Paleoz. cryst. schist |
| | 17 | Kotono-ura | $KO_2{}^E$ | 56 | 17.09 | 8.82 | 0 | |
| | 18 | Taisei Kōkō | $TA^E$ | 56 | 17.39 | 19.62 | 0 | |
| | 19 | Santa | S | 54 | 21.66 | 10.36 | 0 | Alluvium |
| | 20 | Kanaya | $L_1$ | 56 | 5.33 | 15.53 | 0 | Diluvium (River terrace) |
| | 21 | Idakiso | $L_2$ | 54, 56 | 21.82 | 14.64 | 0 | Paleoz. cryst. schist |
| | 22 | Dezima | D | 54 | 20.37 | 6.41 | 0 | Paleoz. cryst. schist |
| | 23 | Hatimaki-yama | $R_1$ | 56 | 28.59 | −1.77 | 0.2 | Izumi sandstone (Upper Cretaceous) |
| | 24 | Todoroki | $R_2$ | 56 | 17.71 | 19.62 | 0 | Paleoz. cryst. schist |
| | 25 | Tōnen | $R_3$ | 56 | 12.38 | 2.70 | 0 | |

かかげ，Table 3 には各観測点の坐標を黒島一等三角点（$\varphi=34°00.'8$N, $\lambda=135°05.'6$ E, $h=121.6$ m）を原点とし，$+x$ を N，$+y$ を E，$+z$ を地下にむけてとつた右手系直角坐標により，km 単位でしめし，基礎の地質のおよそのところを附記した．

これらの観測点の位置は Fig. 1 によつてわかるように，北方の鉢巻山（$R_1$），中松江（NM）と南方の広（H）湯浅（Y）金屋（$L_1$）をのぞき，すべて長瀞変成帯のなかにある．

無線遠隔記録地震計 RTSによる無人観測点をのぞき，1953年以降の，すべての観測点は，関西電力株式会社の業務用通信線を経由して基地に連絡され，有線搬送遠隔刻時装置 LTC により基地におかれた標準時計の刻時を受信し，あるいは有線遠隔記録地震計 LTS による無人観測点として，基地にむけ地震記録を送信するようになつている．基地としては海南変電所（1953, 1956）または琴浦発電所（1954）にもうけた観測点がえらばれた．

なお，これらの観測点のうち，湯浅町耐久高校（Y），海南市海南高校（KA），東野上町大成高校（TA）には，それぞれ1953 年 1 月，1953 年 7 月，1954 年 3 月より常時観測を依託した．その結果については別に報告する予定である．

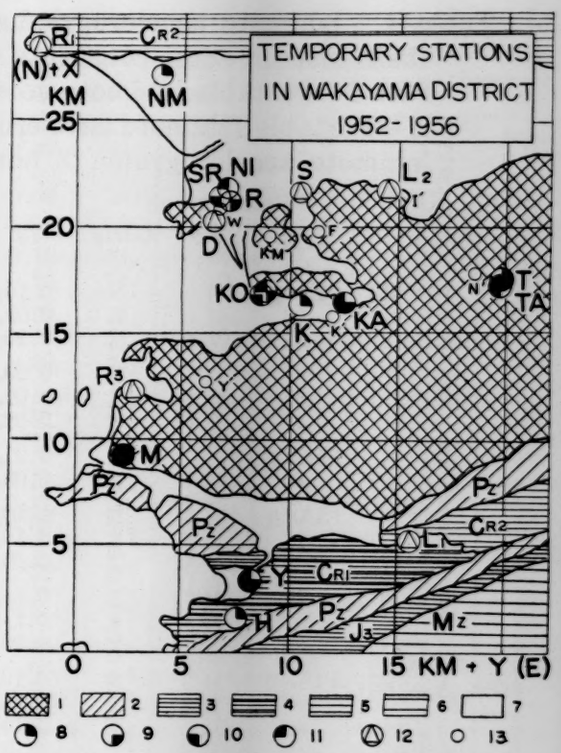


Fig. 1. Locations of temporary stations in the neighbourhood of Wakayama.
Geology. 1–Nagatoro metamorphic rocks (Paleozoic), formerly called as Sambagawa and Mikabu. 2–Paleozoic Titibu formation. 3–Jurassic formation. 4–Lower Cretaceous formation. 5–Upper Cretaceous formation. 6–Unknown Mesozoic (Simanto or Hidaka) formation. 7–Cenozoic formation.
Station. 8～11–Ishimoto accelerograph station at work in 1952, 1953, 1954 and 1956 respectively. 12–Unattended station by LTS and RTS. 13–Temporary station of Kyoto Univ. in 1954 and 1956.

## 3. 使用計器および観測方法

**3·1 石本式加速度計**　臨時精密観測の基準地震計として石本式加速度計3成分（上下動 1，水平動 2）をもちいた．1）第1報[6]でのべたように基本倍率約 200 倍，自己周期 0.1 秒の石本式加速度計の感度でも，1～2 カ月の臨時観測で紀北海岸地方では相当数の

6) S. MIYAMURA, *loc. cit.* 1).

Table 4. Ishimoto accelerographs used in the observations and their instrumental constants calibrated in the field. Type: PIA-I—Portable Ishimoto accelerograph, M = 5 kg ca. PIA-II—Portable Ishimoto accelerograph, M = 15 kg. FIA—Fixed Ishimoto accelerograph, 2 horizontals combined. M = 15 kg.

| Temporary station | | | Seismograph Type | No. | Comp. | Instrumental constants $T_0$ | $V_G$ | $S$ | $V_0$ | $v$ | $\rho$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | s | | mm/gal | | | mm |
| 1952 | 1 | NM | PIA-II | H 3 | N | $0.10_2$ | $16_8$ | — | — | $9.6\pm0.8_2$ | 0.01 |
| | | | 〃 | H 4 | E | $0.09_5$ | $16_8$ | — | — | $9.6\pm0.9_6$ | 0.01 |
| | | | 〃 | V 2 | Z | $0.10_1$ | $19_8$ | — | — | $11\pm1.3$ | 0.00 |
| | 2 | T | 〃 | H 1 | N | $0.09_6$ | $16_8$ | — | — | $10\pm0.8$ | 0.01 |
| | | | 〃 | H 2 | E | $0.09_6$ | $16_8$ | — | — | $7.6\pm0.5_8$ | 0.01 |
| | | | 〃 | V 1 | Z | $0.09_6$ | $19_8$ | — | — | $9.6\pm0.8_2$ | 0.01 |
| | 3 | K | PIA-I | | N | $0.21_0$ | $15_2$ | — | — | $11\pm1.1$ | — |
| | | | 〃 | | Z | $0.08_3$ | $24_0$ | — | — | $6.5\pm0.5_5$ | — |
| | 4 | M | PIA-II | H 5 | N | $0.10_2$ | $16_8$ | — | — | $6.5\pm0.9_6$ | 0.01 |
| | | | 〃 | H 6 | E | $0.10_2$ | $16_8$ | — | — | $8.6\pm0.6_5$ | 0.01 |
| | | | 〃 | V 3 | Z | $0.10_2$ | $19_8$ | — | — | $9.9\pm1.1$ | 0.02 |
| | 5 | H | 〃 | H 7 | N | $0.14_4$ | $16_8$ | — | — | $6.3\pm0.5_8$ | 0.02 |
| | | | 〃 | H 8 | E | $0.11_0$ | $16_8$ | — | — | $7.4\pm0.8_4$ | 0.01 |
| | | | 〃 | CMO | Z | $0.10_2$ | $19_8$ | — | — | $8.8\pm0.8_9$ | — |
| 1953 | 1 | R | PIA-II | H 7 | N | $0.10_4$ | $21_0$ | $0.41_3$ | $15_1$ | $6.0\pm0.9_6$ | — |
| | | | 〃 | H 8 | E | $0.11_0$ | $21_0$ | $0.43_1$ | $14_0$ | $8.0\pm1.3$ | — |
| | | | 〃 | Hagi. | Z | $0.10_2$ | $24_6$ | $0.50_5$ | $18_6$ | $11\pm1.4$ | — |
| | 2 | $KO_1$ | 〃 | H 3 | N | $0.10_2$ | $21_0$ | $0.51_6$ | $19_8$ | $9.4\pm0.9_1$ | — |
| | | | 〃 | H 4 | E | $0.09_5$ | $21_0$ | $0.51_6$ | $22_6$ | $9.2\pm0.6_6$ | — |
| | | | 〃 | V 2 | Z | $0.10_1$ | $24_7$ | $0.44_6$ | $17_4$ | $7.6\pm0.7_9$ | — |
| | 3 | T | 〃 | H 5 | N | $0.10_2$ | $21_0$ | $0.47_9$ | $18_2$ | $4.3\pm0.3_3$ | — |
| | | | 〃 | H 6 | E | $0.10_2$ | $21_0$ | $0.41_0$ | $15_6$ | $9.9\pm1.5$ | — |
| | | | 〃 | V 3 | Z | $0.10_2$ | $24_7$ | $0.48_0$ | $18_3$ | $12\pm1.7$ | — |
| | 4 | KA | FIA Two H. Comp.-type | | N | 0.12 | $21_2$ | $0.56_8$ | $15_6$ | $5.4\pm0.8$ | — |
| | | | | | E | 0.12 | $21_2$ | $0.55_4$ | $15_6$ | $7.4\pm1.6$ | — |
| | | | PIA-I | | Z | $0.08_3$ | $30_0$ | 0.34 | $19_5$ | $9.9\pm0.1_6$ | — |
| | 5 | M | PIA-II | H 1 | N | $0.09_6$ | $21_0$ | $0.46_3$ | $19_9$ | $8.4\pm0.4_9$ | — |
| | | | 〃 | H 2 | E | $0.09_6$ | $21_0$ | $0.46_3$ | $19_9$ | $8.8\pm1.2$ | — |
| | | | 〃 | V 1 | Z | $0.09_6$ | $24_7$ | $0.47_8$ | $20_6$ | $9.2\pm1.1$ | — |
| | 6 | Y | FIA Two H. Comp.-type | | N | 0.12 | $21_0$ | $0.54_4$ | $14_9$ | $13\pm1.9$ | — |
| | | | | | E | 0.12 | $21_0$ | $0.49_7$ | $13_3$ | $9.1\pm1.1$ | — |
| | | | PIA-II | V 4 | Z | $0.10_5$ | $24_7$ | $0.47_4$ | $17_0$ | $10\pm1.1$ | — |
| 1954 | 1 | SR | PIA-II | H 7 | N | $0.10_4$ | $21_0$ | $0.45_1$ | $15_5$ | $8.6\pm1.3$ | — |
| | | | 〃 | H 8 | E | $0.11_0$ | $21_0$ | $0.48_1$ | $16_7$ | $9.7\pm1.1$ | — |
| | | | 〃 | V 3 | Z | $0.10_2$ | $24_7$ | $0.45_4$ | $17_3$ | $8.9\pm1.1$ | — |
| | 2 | $KO_2$ | 〃 | H 3 | N | $0.10_2$ | $21_0$ | $0.45_7$ | $17_4$ | $9.7\pm1.1$ | — |
| | | | 〃 | H 4 | E | $0.09_5$ | $21_0$ | $0.39_4$ | $17_0$ | $10\pm0.8_5$ | — |
| | | | 〃 | V 2 | Z | $0.10_1$ | $24_7$ | $0.46_6$ | $18_0$ | $11\pm1.1$ | — |
| | 3 | KA | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.61_7$ | $16_9$ | $11\pm1.0$ | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.63_7$ | $17_4$ | *$6.8\pm1.1$ | — |
| | | | PIA-I | | Z | $0.08_3$ | $20_0$ | $0.36_2$ | $20_7$ | $9.2\pm1.5$ | — |
| | 4 | TA | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.61_3$ | $16_8$ | $11\pm1.6$ | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.54_3$ | $14_9$ | $11\pm1.1$ | — |
| | | | PIA-I | | Z | $0.11_0$ | $33_0$ | $0.48_5$ | $15_8$ | $11\pm1.3$ | — |

(to be continued)

(continued)

| Temporary station | | | Seismograph Type | No. | Comp. | Instrumental constants $T_0$ (s) | $V_G$ | $S$ (mm/gal) | $V_0$ | $v$ | $\rho$ (nm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1954 | 5 | M | PIA-II | H 1 | N | $0.09_6$ | $21_0$ | $0.45_1$ | $19_2$ | 9.7±1.2 | — |
| | | | 〃 | H 2 | E | $0.09_6$ | $21_0$ | $0.44_1$ | $18_9$ | 10±1.3 | — |
| | | | 〃 | V 1 | Z | $0.09_8$ | $24_7$ | $0.42_3$ | $18_2$ | 9.9±1.5 | — |
| | 6 | Y | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.62_4$ | $17_1$ | 11±1.8 | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.65_2$ | $17_9$ | 11±2.0 | — |
| | | | PIA-II | V 4 | Z | $0.10_5$ | $24_7$ | $0.49_6$ | $17_8$ | 14±1.2 | — |
| 1956 | 1 | NI | PIA-II | H 1 | N | $0.09_6$ | $21_0$ | $0.44_9$ | $19_2$ | 11±0.9 | — |
| | | | 〃 | H 2 | E | $0.09_6$ | $21_0$ | $0.40_5$ | $17_4$ | 9.6±0.8$_1$ | — |
| | | | 〃 | V 1 | Z | $0.09_6$ | $24_7$ | $0.45_2$ | $19_4$ | 10±0.7$_7$ | — |
| | 2 | $KO_3$ | 〃 | H 7 | N | $0.10_4$ | $21_0$ | $0.46_3$ | $16_9$ | 11±0.8$_8$ | — |
| | | | 〃 | H 8 | E | $0.11_0$ | $21_0$ | $0.43_2$ | $14_1$ | 9.8±1.4 | — |
| | | | 〃 | V 3 | Z | $0.10_2$ | $24_7$ | $0.47_0$ | $17_8$ | 8.7±1.0 | — |
| | 3 | KA | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.56_0$ | $15_3$ | 10±0.8$_8$ | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.55_0$ | $15_1$ | *6.4±1.5 | — |
| | | | PIA-I | | Z | $0.08_3$ | $30_0$ | $0.48_0$ | $25_8$ | 11±0.8 | — |
| | 4 | TA | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.61_2$ | $16_8$ | 11±1.0 | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.60_5$ | $16_5$ | 12±1.0 | — |
| | | | PIA-I | | Z | $0.11_0$ | $30_0$ | $0.49_7$ | $16_2$ | *5.5±1.3 | — |
| | 5 | M | PIA-II | H 3 | N | $0.10_2$ | $21_0$ | $0.60_4$ | $16_7$ | 11±1.2 | — |
| | | | 〃 | H 4 | E | $0.09_5$ | $21_0$ | $0.62_6$ | $19_8$ | 12±1.1 | — |
| | | | 〃 | V 2 | Z | $0.10_1$ | $24_7$ | $0.60_1$ | $19_1$ | 11±0.6$_8$ | — |
| | 6 | Y | FIA Two H. Comp.-type | | N | $0.12_0$ | $21_0$ | $0.59_0$ | $16_1$ | 8.2±1.1 | — |
| | | | | | E | $0.12_0$ | $21_0$ | $0.59_0$ | $16_1$ | 6.3±0.9$_9$ | — |
| | | | PIA-II | V 4 | Z | $0.10_5$ | $24_7$ | $0.48_4$ | $17_3$ | 8.7±0.7$_8$ | — |

* コック不良

局地地震を記録できることが推定されたこと．2）上下動と水平動とにそろつた特性をえられること．3）振動数数サイクル以上のはやい振動の卓越する局地地震の記録に適していること．4）自己周期がみぢかいので刻時装置が簡単に附加できること．5）設置，移動，保守等実用上便利にできていること．以上がこの地震計を採用したおもな理由であるが，これはまた同様の理由で地震研究所余震観測班用としても推奨され，整備されていたので[7]，それらを一部流用することができたことも好都合であつた．

この観測にもちいられた石本式加速度計（IA）は主として基本倍率 200 倍の大型携帯用（PIA-II）であり，耐久（Y），海南（KA），大成（TA）各高校では常時観測が依託されてのちは水平2成分として固定型（FIA）が設置された．基本倍率 100 倍の小型携帯用（PIA-I）がもちいられたときもある．

各年度に各観測点でもちいられた石本式加速度計とその常数とは Table 4 にまとめてしめした．この地震計の実地使用の条件についてはすでに筆者と堀実[8]とによつて詳細な実験的研究が報告されているので参照されたい．結局，現地の使用条件下ではふたけたの

7) T. HAGIWARA, Read at the 299th Monthly Meeting of Earthq. Res. Inst., April 21, 1953.

8) S. MIYAMURA *et* M. HORI, "Quelques essais au laboratoire pour utilisation pratique du sismographe accélérometrique du type d'Ishimoto," *Bull. Earthq. Res. Inst.*, **33** (1955), 788–747.

精度で各地震計の特性をそろえることは困難であつた.

固体摩擦は 1952 年度における測定の結果から $\rho \leqq 0.02$ mm であり，記録線のふとさを考慮し，要求される刻時精度をかんがえて，まつたく無視しうることがわかつたので，1953 年以降は特に $\rho$ の測定値を算出しなかつた.

荷重静感度試験からもとめた静感度 $S$ にもとづき計算した基本倍率 $V_0 = (2\pi/T)^2 S$ と拡大てこの腕長比等からもとめた幾何倍率 $V_G$ とは，拡大てこの慣性能率の影響から当然10%程度の差がかんがえられるが，同一地震計で同一幾何倍率の基本倍率が年度によりちがつてるようなのは，幾何倍率の測定の方に誤差があるとみなされる．$V_G$ は調整時の目標値とかんがえていただきたい.

**3·2 電子地震計** 石本式加速度計をそなえた数点のわれわれの観測網では，のちにのべるように1点のみで記録された地震が総数の 60%に達し，4点以上で記録されたものは12%にすぎない．しかも非常にはつきり，するどいたちあがりで初動がよみとれるものは，そのうちの一部にすぎない．したがつて，さらに地震活動がおとろえてきたときには，この観測網での臨時観測はまつたく効果がすくなくなる．そこで観測点の増設と高感度観測とが当然必要になる．高感度観測のためには，光学記録地震計があるが，実用上，経済上もちいにくいし，倍率にも限度がある．当時爆破地震動観測用として，動電型換振器，増幅器，電磁オッシログラフをもちいた地震計がもちいられてきたので，この電磁オッシログラフのかわりに，電力増幅器を附加し，連続使用にたえるペンがき検流計を駆動し，すすがきにより，自然地震の連続観測のできる電子地震計 (ES) をつくつた．この方向の努力はすでに 1950 年ころより表俊一郎[9] によりつづけられていたが，現地で実用化されたのは今回の観測が本邦では最初であろう.

一方，かぎられた人員で必要な多数の観測点を維持運転することは，非常に困難となり，電子地震計もなお学校等に委託観測ができるまでにすすんでなかつたことと，LTC 刻時をあたえうる通信線の利用に制約がおおいために，独立観測点の新設が制限されたので，遠隔記録による無人観測点をもうけ，基地において集中記録をおこなう方式を開発した．これはまた観測精度においても画期的向上を期待できるものである．この観測に導入された有線搬送式遠隔記録地震計 LTS および無線搬送式遠隔記録地震計 RTS については，すでに報告されている[10]のでここには詳述しない.

**3·3 記録装置** 水平2成分固定型加速度計のばあい以外では，今市地震余震の舟生における観測で筆者と秋間哲夫[11]により試用された，3成分用大型円筒記録装置をもちいたが，駆動はワレンモーターで商用交流 (60 c/s, 100 V) によるように変更した．廻転速度は今市地震のときの2倍，2.5 min/Rev. としたので，はぐるまのガタについての条件はさ

9) S. OMOTE, Y. YAMAZAKI and N. KOBAYASHI, Temporary Observation of Volcanic Tremors of Mt. Asama at Asinodaira. Read at the 314th Monthly Meeting of Earthq. Res. Inst., Sept. 28, 1954.

10) S. MIYAMURA *et al.*, *loc. cit.* 4 and 5).

11) S. MIYAMURA und T. AKIMA, "Uber die Beobachtung der Nachbeben des Imaiti-bebens am Dorfe Hunyu, Totigi Provinz," *Bull. Earthq. Res. Inst.*, **28** (1951), 421–433.

らに向上したはずである．固定用のものは従来の軸おくり型式のもので，駆動はおなじくワレンモーターで商用交流により，2.5 min/Rev. であるが，旧式のものであり，はぐるまのガタの点でやや精度がおちる．高感度地震計の記録もすべて上記大型円筒記録装置によりおこなわれた．

このような装置で，1日2回記録紙のとりかえをすることにより，従来の2倍，約4 mn/sec の記録紙速度の観測ができた．

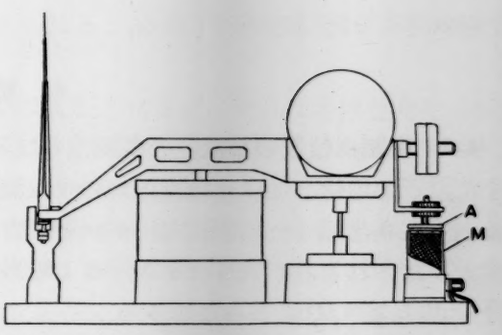


Fig. 2. Time marking device for Ishimoto accelerograph.
A–Iron piece. M–Electromagnet.

**3·4 刻時方式** 1952 年には海南 (K) をのぞく4点では短波受信機により JJY (4 Mc/s) 分秒報時を直接受信して，ふりこに分秒信号による衝撃をあたえ，記象上に刻時した．海南 (K) には LTC の実用試験のため，箕島 (M) で受信した JJY 刻時を LTC 送信機にあたえ，通信線を利用した簡易裸搬でおくりだし，これを受信して刻時した．

1953 年以降は海南変電所 (K) を基地として，JJY により規正された標準時計の分秒刻時を LTC 送信機でおくりだし，各観測点にてこれを LTC 受信機で受信，刻時する LTC 方式を実用化した．

刻時信号をふりこにあたえるには Fig. 2 にしめすように，ふりこに固定した鉄片 A を，固定電磁石 M に負荷される信号電流でひく．電磁石にながれる電流は，受信機の整流出力を1次側とするリレーの2次がわとなつている．

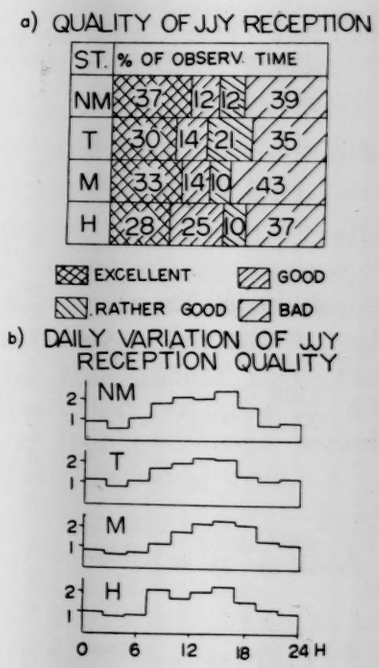


Fig. 3. Result of time mark reception by short wave standard signal, JJY (4Mc/s).

1953 年以降 LTC 方式をとつたのは，1952 年における JJY 直接受信方式が，つぎのような理由で連続観測用として適当でないとかんがえられたからである．1952 年における4点での JJY の刻時状況を優，良，可，不可の4階級にわけて評価し，それぞれの通算時間数の総観測時間数に対する比率をもとめると Fig. 3 のようになり，ほぼ 1/3 程度の時間良好な刻時をえられるにすぎないことが判明した．しかもある点で受信が良好なときに，他の点では不良のばあいもあるので，各点でひとつの地震を記録したときに，それらの点の刻時がそろつて良好であるということは，きわめてまれになつてしまう．もちろん受信方式，受信機の改良，受信の頻繁な監視などにより，このような短波報時受信のフェーディング，混信等による不安定はある程度さけられるであろうが，LTC 方式の方がさらに確実性がたかいとかんが

えられるにいたつたからである.

## 4. 観測精度

**4·1 観測点位置の精度** 各観測点の位置は，地理調査所測量用航空写真により確認できた附近の地物または三角点等から平板測量によりみちびき，黒島一等三角点を原点とする右手直角坐標（$+x$ を北方，$+y$ を東方）であらわしたが，その精度はほぼ ±10 m 程度とみなされる．$z$ 坐標は5万分の1地形図からよみとつたが ±10 m 程度であり，大部分の点は $z=0$ m とみなしうる.

**4·2 時刻精度** すでにのべたように，秒の刻時が各点共通に記入されているので，初

**Table 5. Mean lengths of a second in 25 seconds before arbitrarily selected seismograms.**

| No. | Date | Time | Station | Comp. | Mean length of a second |
|---|---|---|---|---|---|
| | 1952 | h m | | | mm |
| 1 | XI 5 | 11.47 | NM | N | 3.93±0.11 |
| | | | 〃 | E | 3.95±0.12 |
| | | | 〃 | Z | 3.97±0.08 |
| | | | T | N | 3.91±0.12 |
| | | | 〃 | E | 3.96±0.08 |
| | | | 〃 | Z | 3.97±0.08 |
| | | | H | E | 3.93±0.22 |
| 2 | 1952 XI 10 | 19.50 | T | N | 3.95±0.07 |
| | | | 〃 | E | 3.97±0.10 |
| | | | 〃 | Z | 3.96±0.07 |
| | | | H | N | 3.99±0.07 |
| 3 | 1952 XI 16 | 12.17 | T | N | 3.86±0.26 |
| | | | 〃 | E | 3.86±0.21 |
| | | | 〃 | Z | 3.86±0.22 |
| | | | M | N | 3.91±0.21 |
| | | | 〃 | E | 3.90±0.24 |
| 4 | 1952 XI 22 | 21.32 | M | N | 3.80±0.17 |
| | | | 〃 | E | 3.80±0.18 |
| | | | 〃 | Z | 3.80±0.19 |
| 5 | 1952 XI 24 | 18.35 | NM | N | 3.86±0.11 |
| | | | 〃 | E | 3.82±0.27 |
| | | | T | N | 3.88±0.11 |
| | | | 〃 | E | 3.82±0.13 |
| | | | 〃 | Z | 3.82±0.10 |
| | | | M | N | 3.83±0.08 |
| | | | 〃 | E | 3.83±0.07 |
| 6 | 1952 XI 28 | 22.15 | NM | E | 3.88±0.11 |
| | | | 〃 | Z | 3.89±0.09 |
| | | | T | E | 3.87±0.14 |
| | | | 〃 | Z | 3.86±0.09 |
| | | | M | N | 3.87±0.02 |
| | | | 〃 | E | 3.81±0.07 |
| 7 | 1953 XI 16 | 04.59 | R | N | 3.84±0.07 |
| 7 | | | KO | N | 3.83±0.07 |
| | | | KA | 〃 | 3.38±0.12* |
| | | | K | 〃 | 3.87±0.06 |
| | | | T | 〃 | 3.84±0.26 |
| | | | M | 〃 | 3.83±0.05 |
| | | | Y | 〃 | 3.37±0.07* |
| 8 | 1953 XI 19 | 07.85 | R | N | 3.84±0.08 |
| | | | KO | 〃 | 3.86±0.06 |
| | | | KA | 〃 | 3.36±0.10* |
| | | | K | 〃 | 3.87±0.11 |
| | | | M | 〃 | 3.85±0.08 |
| | | | Y | 〃 | 3.34±0.07* |
| 9 | 1953 XI 21 | 01.51 | R | N | 3.80±0.05 |
| | | | KO | 〃 | 3.90±0.06 |
| | | | KA | 〃 | 3.38±0.09 |
| | | | K | 〃 | 3.89±0.06 |
| | | | T | 〃 | 3.86±0.06 |
| | | | M | 〃 | 3.89±0.06 |
| 10 | 1954 XII 10 | 03.45 | KO | N | 3.96±0.06 |
| | | | 〃 | E | 3.94±0.06 |
| | | | 〃 | Z | 3.96±0.06 |
| | | | KA | N | 3.51±0.12* |
| | | | 〃 | E | 3.49±0.13* |
| | | | M | N | 3.94±0.05 |
| | | | 〃 | E | 3.92±0.05 |
| | | | 〃 | Z | 3.92±0.05 |
| | | | Y | N | 3.57±0.11* |
| | | | 〃 | E | 3.53±0.09* |
| | | | 〃 | Z | 3.49±0.18* |
| 11 | 1954 XI 12 | 22.15 | KO | N | 3.94±0.08 |
| | | | 〃 | E | 3.93±0.06 |
| | | | 〃 | Z | 3.93±0.07 |
| | | | T | N | 3.35±0.05* |
| | | | M | 〃 | 3.92±0.05 |
| | | | Y | 〃 | 3.41±0.08* |
| | | | 〃 | E | 3.40±0.12* |

* Diameter of recording drum is 200 mm, while the other drum has 600 mm circumference.

動時刻は1秒間の廻転不同だけの範囲におさえられることはいうまでもない．分刻時のみのばあいにくらべ非常に有利である．

1秒間の記象上のながさは交流周波数の変動に支配されるが，それは急激な変化は影響ないので，11回の任意の地震の記録で，初動前25秒間の1秒のながさのをよみとると，Table 5 のような結果となり，1～7%の分散をしめすにすぎない．したがつて，地震の直前の数秒の平均値から，刻時のみわけられない振動中の時刻を推定しても数パーセントの精度が確保できるわけである．初動時刻については ±0.02 sec，$S$ 時刻または $S$–$P$ 時間については $S$–$P$ 時間の数パーセント以下の精度とかんがえてよい．なお，記録紙のつぎめにまたがる1秒のながさはあきらかに若干ののびがあるので，注意を要する．

以上のべた刻時精度からみて，位相受震時の精度はむしろその明確なる同定に依存することがあきらかである．

**4·3 絶対時刻** JJY 直接記入のばあいは問題がないが，標準時計をもちいる LTC 方式のばあいは，えられた時刻はこの標準時計による地方時になるわけで，海南地方時（KLT）と称する．これはわれわれの観測網の資料を気象台，京大など他の観測網の資料とくらべるときには，絶対時刻（日本標準時 JST）になおす必要があり，そのため基地の標準時計は1日2回以上 JJY 分秒報時と比較した．1分以上のちがいは分をもどしてかぞえているので生じない．使用した時計の分刻時は盤面正時より5秒おくれている．われわれの整理では今後特にことわらないかぎり1953～1956 では KLT をもちいるであろう．

**4·4 地震計の精度** 石本式加速度計の常数決定の精度については既報[12]のごとくで現地における使用状況では5%の精度ですべての地震計をそろえることは不可能であり，波形，振巾については 10% 程度の範囲内で議論するにとどめなくてはならないとかんがえられる．位相差については 10% としても時間としては 1/100 秒以下のずれであり，計測には支障ないものとみとめられる．

電子地震計の精度については当時なお充分検討されてなかつたし，特に感度をそろえるような考慮ははらわれなかつた．増幅器等電子回路の利得はほぼ Table 6 のようなものであり，換振器は約 0.6 volt/kine の爆破グループ型小型換振器が使用された．

**Table 6. Gains of seismograph amplifiers. Sensitivity of the transducers used was about 0.6 volt/kine at 10 c/s, free oscillation period of which being 3 c/s.**

| Year | Station | Sensitivity $\mu V$ eff. value/mm |
|---|---|---|
| 1953 | $K^E$ | 100 |
| 1954 | $KO^E$ | 10 |
| 1954 | S | 150 |
| 1954 | D | 30 |
| 1956 | $KO^E$ | 10 |

12) S. MIYAMURA et M. HORI, *loc. cit.* 8).

## 5. 観測成果概要

**5·1 観測地震数** 各年度各観測点における観測実動日数，記録地震総数，および毎日あたり回数を Table 7 にしめす．器械記録地震計（石本式加速度計 IA）によるものは K (1952) をのぞきすべてほぼ同一感度であり，観測開始終了日時の若干のずれ，記録紙交換中の短時間欠測および若干の故障による欠測等のため多少のちがいはあるが，ほぼその附近のその時期の地震活動をしめすものとかんがえられる．K (1952) は倍率約 1/2 であるから，地震数は大体倍にしてかんがえてよい．電子地震計による観測の方は観測点の雑微動水準により種々のちがつた感度でおこなわれているので，このような意味で相互の比較をおこなうことはできないことは当然である．

Table 7a. Effective observation periods and numbers of recorded earthquakes at the temporary stations equipped with Ishimoto accelerographs of approximately same sensitivity.

| Year | Station | Period (days) | Earthq. Numbers | | Year | Station | Period (days) | Earthq. Numbers | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Per day | | | | Total | Per day |
| 1952 | NM | 53 | 42 | 0.79 | 1954 | M | 45 | 24 | 0.53 |
| | K* | 52 | 37 | 0.71 | | Y | 45 | 56 | 1.24 |
| | T | 55 | 62 | 1.13 | 1956 | NI | 39.6 | 48 | 1.21 |
| | M | 54 | 40 | 0.74 | | KO | 29.7 | 97 | 3.17 |
| | H | 55 | 36 | 0.65 | | KA | 42.7 | 45 | 1.05 |
| 1953 | R | 56.5 | 89 | 1.57 | | TA | 28 | 22 | 0.79 |
| | KO | 54 | 110 | 2.04 | | M | 32 | 16 | 0.50 |
| | KA | 56 | 100 | 1.79 | | Y | 43 | 45 | 1.05 |
| | T | 56 | 58 | 1.03 | Mean through 1952～1956 | | | | |
| | M | 57.5 | 57 | 0.99 | | R,SR,NI | 133.6 | 187 | 1.40 |
| | Y | 57.5 | 65 | 1.13 | | KO | 123.7 | 277 | 2.24 |
| 1954 | SR | 37.5 | 50 | 1.33 | | KA | 138.7 | 188 | 1.36 |
| | KO | 40 | 70 | 1.75 | | T, TA | 101.5 | 86 | 0.85 |
| | KA | 40 | 43 | 1.07 | | M | 134.5 | 166 | 1.14 |
| | TA | 17.5 | 6 | 0.34 | | Y, H | 200.5 | 202 | 1.01 |

* Sensitivity was about half of the others.

Table 7b. Effective observation periods and numbers of recorded earthquakes at the temporary stations equipped with electronic seismographs of similar frequency characteristics but of different sensitivities.

| Year | Station | Instrument | Period (days) | Earthq. Numbers | |
|---|---|---|---|---|---|
| | | | | Total | Per day |
| 1953 | K$^{E}$ | ES | 53 | 290 | 5.48 |
| 1954 | D | RTS-I | 35 | 348 | 9.94 |
| 〃 | S | LTS | 36 | 80 | 2.22 |
| 〃 | KO$^{E}$ | ES | 32 | 649 | 20.2 |
| 1956 | KO$^{E}$ | ES | 30 | 1175 | 39.2 |

Table 8 は石本式加速度計による観測結果を整理してどの観測点乃至観測点のくみあわせで，いくつの地震が記録されたかをしめしたものである．1点のみで観測されたものが総数の 60% に達し，

Table 8. Numbers of earthquakes recorded at the temporary stations and at combinations of the stations.

| Number of stations | Combination of stations* | Number of recorded shocks | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1952 ($X=NM$, $Y=H$) | | 1953 ($X=R$, $Y=Y$) | | 1954 ($X=SR$, $Y=Y$) | | 1956 ($X=NI$, $Y=Y$) | | |
| 1 | X | 51 | 77 (62%) | 34 | 132 (56%) | 11 | 72 (54%) | 18 | 116 (68%) | 397 (60%) |
| | KO | 7 (K) | | 30 | | 20 | | 59 | | |
| | KA | | | 21 | | 9 | | 8 | | |
| | T | 26 | | 6 | | 0 | | 6 | | |
| | M | 15 | | 8 | | 1 | | 5 | | |
| | Y | 14 | | 33 | | 31 | | 20 | | |
| 2 | X, KO | 4 | 19 (15%) | 10 | 41 (17%) | 14 | 31 (23%) | 7 | 31 (18%) | 122 (18%) |
| | X, KA | | | 5 | | 1 | | 5 | | |
| | KO, KA | 0 | | 11 | | 7 | | 6 | | |
| | T, KO | 2 | | 0 | | 0 | | 0 | | |
| | T, KA | | | 3 | | 0 | | 1 | | |
| | M, KO | 1 | | 1 | | 0 | | 1 | | |
| | M, KA | | | 1 | | 0 | | 0 | | |
| | Y, KO | 0 | | 0 | | 1 | | 4 | | |
| | Y, KA | | | 2 | | 2 | | 3 | | |
| | X, T | 5 | | 0 | | 0 | | 1 | | |
| | X, M | 0 | | 0 | | 0 | | 0 | | |
| | X, Y | 0 | | 0 | | 0 | | 0 | | |
| | T, M | 0 | | 3 | | 0 | | 0 | | |
| | T, Y | 3 | | 0 | | 1 | | 0 | | |
| | M, Y | 4 | | 5 | | 5 | | 3 | | |
| 3 | X, KO, KA | 0 | 13 (11%) | 8 | 18 (8%) | 8 | 14 (11%) | 3 | 13 (8%) | 58 (9%) |
| | T, KO, KA | 0 | | 5 | | 0 | | 0 | | |
| | M, KO, KA | 0 | | 1 | | 1 | | 1 | | |
| | Y, KO, KA | 0 | | 0 | | 0 | | 1 | | |
| | X, T, KO | 4 | | 1 | | 0 | | 2 | | |
| | X, T, KA | | | 0 | | 0 | | 2 | | |
| | X, M, KO | 1 | | 0 | | 1 | | 0 | | |
| | X, M, KA | | | 0 | | 0 | | 0 | | |
| | X, Y, KO | 1 | | 0 | | 2 | | 1 | | |
| | X, Y, KA | | | 0 | | 0 | | 0 | | |
| | T, M, KO | 4 | | 2 | | 0 | | 0 | | |
| | T, M, KA | | | 0 | | 0 | | 0 | | |
| | T, Y, KO | 0 | | 0 | | 0 | | 0 | | |
| | T, Y, KA | | | 0 | | 0 | | 2 | | |
| | M, Y, KO | 0 | | 0 | | 1 | | 0 | | |
| | M, Y, KA | | | 0 | | 1 | | 1 | | |
| | X, T, M | 0 | | 0 | | 0 | | 0 | | |
| | X, T, Y | 1 | | 0 | | 0 | | 0 | | |
| | X, M, Y | 0 | | 0 | | 0 | | 0 | | |
| | T, M, Y | 2 | | 1 | | 0 | | 0 | | |

(to be continued)

(continued)

| Number of stations | Combination of stations* | Number of recorded shocks | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1952 ($X=NM$, $Y=H$) | | 1953 ($X=R$, $Y=Y$) | | 1954 ($Y=SR$, $Y=Y$) | | 1956 ($X=NI$, $Y=Y$) | | |
| 4 | X, T, KO, KA | 0 | | 8 | | 0 | | 2 | | |
| | X, M, KO, KA | 0 | | 4 | | 3 | | 0 | | |
| | X, Y, KO, KA | 0 | | 0 | | 1 | | 1 | | |
| | T, M, KO, KA | 0 | | 3 | | 0 | | 0 | | |
| | T, Y, KO, KA | 0 | | 1 | | 0 | | 0 | | |
| | M, Y, KO, KA | 0 | | 0 | | 1 | | 2 | | |
| | T, M, Y, KO | 4 | 13 (11%) | 0 | 22 (9%) | 1 | 8 (6%) | 0 | 6 (4%) | 49 (7%) |
| | T, M, Y, KA | | | 4 | | 0 | | 0 | | |
| | X, T, M, KO | 4 | | 2 | | 0 | | 0 | | |
| | X, T, M, KA | | | 0 | | 1 | | 0 | | |
| | X, T, Y, KO | 2 | | 0 | | 0 | | 0 | | |
| | X, T, Y, KA | | | 0 | | 0 | | 1 | | |
| | X, M, Y, KO | 0 | | 0 | | 1 | | 0 | | |
| | X, M, Y, KA | | | 0 | | 0 | | 0 | | |
| | X, T, M, Y | 3 | | 0 | | 0 | | 0 | | |
| 5 | X, T, M, KO, KA | 0 | | 4 | | 0 | | 0 | | |
| | X, T, Y, KO, KA | 0 | | 2 | | 1 | | 3 | | |
| | X, M, Y, KO, KA | 0 | 2 (2%) | 2 | 14 (6%) | 5 | 8 (6%) | 1 | 5 (3%) | 29 (4%) |
| | T, M, Y, KO, KA | 0 | | 6 | | 1 | | 1 | | |
| | X, T, M, Y, KO | 2 | | 0 | | 1 | | 0 | | |
| | X, T, M, Y, KA | | | 0 | | 0 | | 0 | | |
| 6 | X, T, M, Y, KO, KA | | | 9 | (4%) | 0 | (0%) | 1 | (1%) | 10 (1%) |
| Total | | | 124 (101%) | | 236 (100%) | | 133 (100%) | | 172 (102%) | 665 (99%) |

発震時刻による震源要素決定の必要最小観測数である5点以上で観測されたものは総数の5%にすぎず，初期微動時間法による最小数4点以上をとつても 12% 程度にすぎない．しかも，これらのうちには充分明確に位相時刻をよみとりえない記録もふくまれているのであるから，この観測の効率はあまりよくなかつたといえる．すべての観測点で，おおかれすくなかれ，そこだけで観測された地震のあることは，地震がこの観測網の範囲内にあまねく分布して発生していることをしめし，しかも4点以上の観測点で共通に観測された地震のすくないことは，これらの地震が比較的震源深度のあさい，規模のちいさいものであり，したがつて震央距離による減衰が非常にはやいものであることをしめしている．これらの点からも，観測点の増設乃至高感度化が当然要求されることがわかるのである．

**5·2 初期微動時間** 各年度各観測点でえられた初期微動時間 $t_{S-P}$ の頻度とその総数に対する百分率を Table 9 にしめす．百分率 10% 以上の部分を実線，5% 以上の部分を点線でかこんである．Fig. 4 にまとめた頻度分布の型式を通覧してさらにはつきりするが，これらは 1) ほとんど 0.5～1.5 sec にあつまつているa–タイプ，2) 1.0 sec 以下のものがすくなく，主として 1.0～2.0 sec に集中，2.0 sec 以上のものもかなりあるb–タイプ，(3 両者の中間型で，0.5～2.0sec のあいだにひろがるab–タイプに大別することができる．

Table 9. Frequency of $S$-$P$ intervals observed at the temporary stations in the neighbourhood of Wakayama. Station name abbreviations are referred to Tables 1～2.

| 1952 / $t_{S-P}$ | NM | | K | | T | | M | | H | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % | | % |
| ≥ 0.0s | 0 | 0.0 | 4 | 11.1 | 2 | 3.3 | 2 | 5.1 | 1 | 3.0 |
| ≥ 0.5 | 2 | 5.0 | 8 | 22.2 | 11 | 18.3 | 8 | 20.5 | 1 | 3.0 |
| ≥ 1.0 | 17 | 42.5 | 14 | 38.9 | 20 | 33.4 | 12 | 30.8 | 10 | 30.4 |
| ≥ 1.5 | 9 | 22.5 | 2 | 5.6 | 10 | 16.6 | 8 | 20.5 | 10 | 30.4 |
| ≥ 2.0 | 4 | 10.0 | 0 | 0.0 | 5 | 8.3 | 3 | 7.7 | 2 | 6.1 |
| ≥ 2.5 | 1 | 2.5 | 0 | 0.0 | 3 | 5.0 | 0 | 0.0 | 1 | 3.0 |
| ≥ 3.0 | 1 | 2.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥ 3.5 | 0 | 0.0 | 0 | 0.0 | 1 | 1.7 | 0 | 0.0 | 0 | 0.0 |
| ≥ 4.0 | 0 | 0.0 | 1 | 2.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥ 4.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 3.0 |
| ≥ 5.0 | 1 | 2.5 | 0 | 0.0 | 1 | 1.7 | 3 | 7.7 | 3 | 9.1 |
| ≥ 5.5 | 0 | 0.0 | 2 | 5.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥ 6.0 | 0 | 0.0 | 1 | 2.8 | 3 | 5.0 | 2 | 5.1 | 0 | 0.0 |
| ≥ 6.5 | 1 | 2.5 | 1 | 2.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥ 7.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.7 | 0 | 0.0 | 0 | 0.0 |
| ≥ 7.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 3.0 |
| ≥ 8.0 | 0 | 0.0 | 1 | 2.8 | 0 | 0.0 | 1 | 2.6 | 1 | 3.0 |
| ≥ 8.5 | 1 | 2.5 | 1 | 2.8 | 0 | 0.0 | 0 | 0.0 | 1 | 3.0 |
| ≥ 9.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.7 | 0 | 0.0 | 0 | 0.0 |
| ≥ 9.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥10. | 3 | 7.5 | 1 | 2.8 | 2 | 3.3 | 0 | 0.0 | 1 | 3.0 |
| Subtotal | 40 | 100.0 | 36 | 100.2 | 60 | 100.0 | 39 | 100.0 | 33 | 100.0 |
| Uncertain | 2 | | 1 | | 2 | | 1 | | 3 | |
| Total | 42 | | 37 | | 62 | | 40 | | 36 | |
| $\bar{\tau}_m$ | 0s.85 | | 0s.41 | | 0s.45 | | 0s.54 | | 0s.98 | |
| Type | b | | a | | ab | | ab | | b | |

(to be continued)

(continued)

| 1953 $t_{S-P}$ | R | | KO | | KA | | T | | M | | Y | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s | | % | | % | | % | | % | | % | | % |
| ≧ 0.0 | 1 | 2.3 | 6 | 5.5 | 13 | 13.3 | 0 | 0.0 | 1 | 1.8 | 1 | 1.9 |
| ≦ 0.5 | 40 | 46.0 | 38 | 34.5 | 20 | 20.4 | 3 | 5.3 | 19 | 35.2 | 6 | 11.5 |
| ≦ 1.0 | 37 | 42.5 | 49 | 44.5 | 32 | 32.7 | 8 | 14.0 | 18 | 33.3 | 15 | 28.9 |
| ≧ 1.5 | 4 | 4·6 | 12 | 10.9 | 21 | 21.4 | 20 | 35.1 | 1 | 1.9 | 10 | 19.2 |
| ≧ 2.0 | 1 | 1.1 | 0 | 0.0 | 4 | 4.1 | 10 | 17.5 | 5 | 9.3 | 7 | 13.4 |
| ≧ 2.5 | 1 | 1.1 | 2 | 1.8 | 2 | 2.0 | 5 | 8.8 | 4 | 7.4 | 3 | 5.8 |
| ≧ 3.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 3.5 | 0 | 0.0 | 1 | 1.9 |
| ≧ 3.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 3.7 | 2 | 3.8 |
| ≧ 4.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 4.5 | 1 | 1.1 | 1 | 0.9 | 1 | 1.0 | 2 | 3.5 | 0 | 0.0 | 0 | 0.0 |
| ≧ 5.0 | 0 | 0.0 | 1 | 0.9 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.9 |
| ≧ 5.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.8 | 0 | 0.0 |
| ≧ 6.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.0 | 1 | 1.8 | 0 | 0.0 | 1 | 1.9 |
| ≧ 6.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.8 | 1 | 1.9 |
| ≧ 7.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 7.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.9 |
| ≧ 8.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 8.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.8 | 0 | 0.0 | 0 | 0.0 |
| ≧ 9.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 1.8 | 1 | 1.8 | 0 | 0.0 |
| ≧ 9.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧10. | 0 | 1.1 | 1 | 0.9 | 4 | 4.1 | 4 | 7.0 | 1 | 1.8 | 3 | 5.8 |
| Subtotal | 87 | 99.8 | 110 | 99.9 | 98 | 100.1 | 57 | 100.1 | 54 | 99.8 | 52 | 99.8 |
| Uncertain | 2 | | 0 | | 2 | | 1 | | 3 | | 13 | |
| Total | 89 | | 110 | | 100 | | 58 | | 57 | | 65 | |
| $\bar{\tau}_m$ | 0s.4 | | 0s.41 | | 0s.39 | | 0s.91 | | 0s.68 | | 0s.77 | |
| Type | a | | a | | ab | | b | | ab | | b | |

(to be continued)

(continued)

| 1954 $t_{S-P}$ | SR | | KO | | KA | | TA | | M | | Y | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % | | % | | % |
| ≧ 0.0s | 0 | 0.0 | 0 | 0.0 | 1 | 2.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 0.5 | 20 | 40.0 | 33 | 47.2 | 13 | 30.2 | 0 | 0.0 | 6 | 25.0 | 1 | 1.9 |
| ≧ 1.0 | 27 | 54.0 | 28 | 40.0 | 15 | 34.9 | 2 | 32.0 | 4 | 16.7 | 11 | 20.8 |
| ≧ 1.5 | 2 | 4.0 | 5 | 7.1 | 7 | 16.3 | 1 | 17.0 | 2 | 8.3 | 17 | 32.1 |
| ≧ 2.0 | 0 | 0.0 | 1 | 1.4 | 1 | 2.3 | 0 | 0.0 | 4 | 16.7 | 6 | 11.3 |
| ≧ 2.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 4.2 | 5 | 9.4 |
| ≧ 3.0 | 0 | 0.0 | 1 | 1.4 | 0 | 0.0 | 0 | 0.0 | 1 | 4.2 | 5 | 9.4 |
| ≧ 3.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 17.0 | 1 | 4.2 | 0 | 0.0 |
| ≧ 4.0 | 0 | 0.0 | 1 | 1.4 | 2 | 4.7 | 0 | 0.0 | 0 | 0.0 | 1 | 1.9 |
| ≧ 4.5 | 0 | 0.0 | 0 | 0.0 | 1 | 2.3 | 1 | 17.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 5.0 | 1 | 2.0 | 0 | 0.0 | 2 | 4.7 | 0 | 0.0 | 0 | 0.0 | 2 | 3.8 |
| ≧ 5.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 3.8 |
| ≧ 6.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 8.3 | 1 | 1.9 |
| ≧ 6.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 7.0 | 0 | 0.0 | 1 | 1.4 | 0 | 0.0 | 0 | 0.0 | 1 | 4.2 | 0 | 0.0 |
| ≧ 7.5 | 0 | 0.0 | 0 | 0.0 | 1 | 2.3 | 1 | 17.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 8.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 8.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 9.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 9.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 4.2 | 1 | 1.9 |
| ≧10. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 4.2 | 1 | 1.9 |
| Subtotal | 50 | 100.0 | 70 | 99.9 | 43 | 100.1 | 6 | 100.0 | 24 | 100.2 | 53 | 100.1 |
| Uncertain | 1 | | 0 | | 0 | | 0 | | 1 | | 3 | |
| Total | 51 | | 70 | | 43 | | 6 | | 25 | | 56 | |
| $\bar{\tau}_m$ | 0s.57 | | 0s.61 | | 0s.50 | | (1s.0) | | 0s.77 | | 1s.00 | |
| Type | a | | a | | ab | | b | | ab | | b | |

(to be continued)

(continued)

| 1956 / $t_{S-P}$ | NI | | KO | | KA | | TA | | M | | Y | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | % | | % | | % | | % | | % |
| ≧ 0.0 | 4 | 10.0 | 2 | 2.2 | 1 | 2.2 | 1 | 4.5 | 0 | 0.0 | 0 | 0.0 |
| ≧ 0.5 | 18 | 45.0 | 40 | 43.9 | 9 | 20.0 | 3 | 13.6 | 7 | 50.0 | 3 | 8.1 |
| ≧ 1.0 | 14 | 35.0 | 32 | 35.2 | 14 | 31.2 | 8 | 36.4 | 3 | 21.4 | 12 | 32.5 |
| ≧ 1.5 | 1 | 2.5 | 8 | 8.8 | 14 | 31.2 | 3 | 13.6 | 3 | 21.4 | 9 | 24.3 |
| ≧ 2.0 | 1 | 2.5 | 4 | 4.4 | 3 | 6.8 | 4 | 18.2 | 0 | 0.0 | 8 | 21.6 |
| ≧ 2.5 | 1 | 2.5 | 2 | 2.2 | 0 | 0.0 | 1 | 4.5 | 0 | 0.0 | 1 | 2.7 |
| ≧ 3.0 | 0 | 0.0 | 0 | 0.0 | 1 | 2.2 | 2 | 9.1 | 1 | 7.1 | 2 | 5.6 |
| ≧ 3.5 | 0 | 0.0 | 1 | 1.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 4.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 4.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 5.0 | 0 | 0.0 | 0 | 0.0 | 2 | 4.4 | 0 | 0.0 | 0 | 0.0 | 1 | 2.7 |
| ≧ 5.5 | 1 | 2.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 6.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 6.5 | 0 | 0.0 | 1 | 1.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 7.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 7.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 8.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 8.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 9.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧ 9.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≧10. | 0 | 0.0 | 1 | 1.1 | 1 | 2.2 | 0 | 0.0 | 0 | 0.0 | 1 | 2.7 |
| Subtotal | 40 | 100.0 | 91 | 100.0 | 54 | 100.2 | 22 | 99.9 | 14 | 99.9 | 37 | 100.2 |
| Uncertain | 8 | | 6 | | 0 | | 0 | | 2 | | 8 | |
| Total | 48 | | 97 | | 45 | | 22 | | 16 | | 45 | |
| $\tau_m$ | 0$^s$.45 | | 0$^s$.53 | | 0$^s$.51 | | 0$^s$.50 | | 0$^s$.83 | | 0$^s$.93 | |
| Type | a | | a | | ab | | ab | | ab | | b | |

(to be continued)

(continued)

| $t_{S-P}$ | 1953 K | | 1954 KO$^{E}$ | | 1954 S | | 1954 D | | 4956 KO$^{E}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| s | | % | | % | | % | | % | | % |
| ≥ 0.0 | 59 | 21.8 | 0 | 0.0 | 0 | 0.0 | 2 | 0.6 | 12 | 0.1 |
| ≥ 0.5 | 70 | 25.8 | 246 | 39.2 | 28 | 32.9 | 190 | 58.9 | 495 | 43.3 |
| ≥ 1.0 | 83 | 30.6 | 239 | 38.1 | 35 | 41.2 | 89 | 27.6 | 441 | 38.6 |
| ≥ 1.5 | 29 | 10.7 | 51 | 8.1 | 9 | 10.6 | 10 | 3.1 | 81 | 7.1 |
| ≥ 2.0 | 7 | 2.6 | 10 | 1.9 | 2 | 2.4 | 5 | 1.5 | 31 | 2.7 |
| ≥ 2.5 | 3 | 1.1 | 17 | 2.7 | 2 | 2.4 | 6 | 1.9 | 9 | 0.8 |
| ≥ 3.0 | 1 | 0.4 | 8 | 1.3 | 0 | 0.0 | 2 | 0.6 | 6 | 0.5 |
| ≥ 3.5 | 0 | 0.0 | 11 | 1.8 | 0 | 0.0 | 6 | 1.9 | 4 | 0.3 |
| ≥ 4.0 | 3 | 1.1 | 3 | 0.5 | 0 | 0.0 | 0 | 0.0 | 6 | 0.5 |
| ≥ 4.5 | 5 | 1.8 | 3 | 0.5 | 1 | 1.2 | 3 | 0.9 | 9 | 0.8 |
| ≥ 5.0 | 0 | 0.0 | 5 | 0.8 | 0 | 0.0 | 0 | 0.0 | 2 | 0.2 |
| ≥ 5.5 | 1 | 0.4 | 1 | 0.2 | 0 | 0.0 | 1 | 0.3 | 3 | 0.3 |
| ≥ 6.0 | 0 | 0.0 | 5 | 0.8 | 3 | 3.5 | 2 | 0.6 | 3 | 0.3 |
| ≥ 6.5 | 3 | 1.1 | 3 | 0.5 | 1 | 1.2 | 1 | 0.3 | 5 | 0.4 |
| ≥ 7.0 | 1 | 0.4 | 2 | 0.3 | 1 | 1.2 | 0 | 0.0 | 3 | 0.3 |
| ≥ 7.5 | 2 | 0.7 | 4 | 0.6 | 1 | 1.2 | 1 | 0.3 | 3 | 0.3 |
| ≥ 8.0 | 1 | 0.4 | 2 | 0.3 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 |
| ≥ 8.5 | 0 | 0.0 | 4 | 0.6 | 0 | 0.0 | 1 | 0.3 | 1 | 0.1 |
| ≥ 9.0 | 0 | 0.0 | 2 | 0.3 | 0 | 0.0 | 0 | 0.0 | 2 | 0.2 |
| ≥ 9.5 | 1 | 0.4 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| ≥10. | 2 | 0.7 | 10 | 1.6 | 2 | 2.4 | 3 | 0.9 | 28 | 2.4 |
| Subtotal | 271 | 100.0 | 627 | 100.0 | 85 | 100.2 | 323 | 100.1 | 1144 | 100.2 |
| Uncertain | 91 | | 23 | | 5 | | 26 | | 31 | |
| Total | 290 | | 650 | | 90 | | 349 | | 1175 | |
| $\bar{\tau}_m$ | 0$^{s}$.39 | | 0$^{s}$.64 | | 0$^{s}$.61 | | 0$^{s}$.60 | | 0$^{s}$.57 | |
| Type | a | | a | | a | | a | | a | |

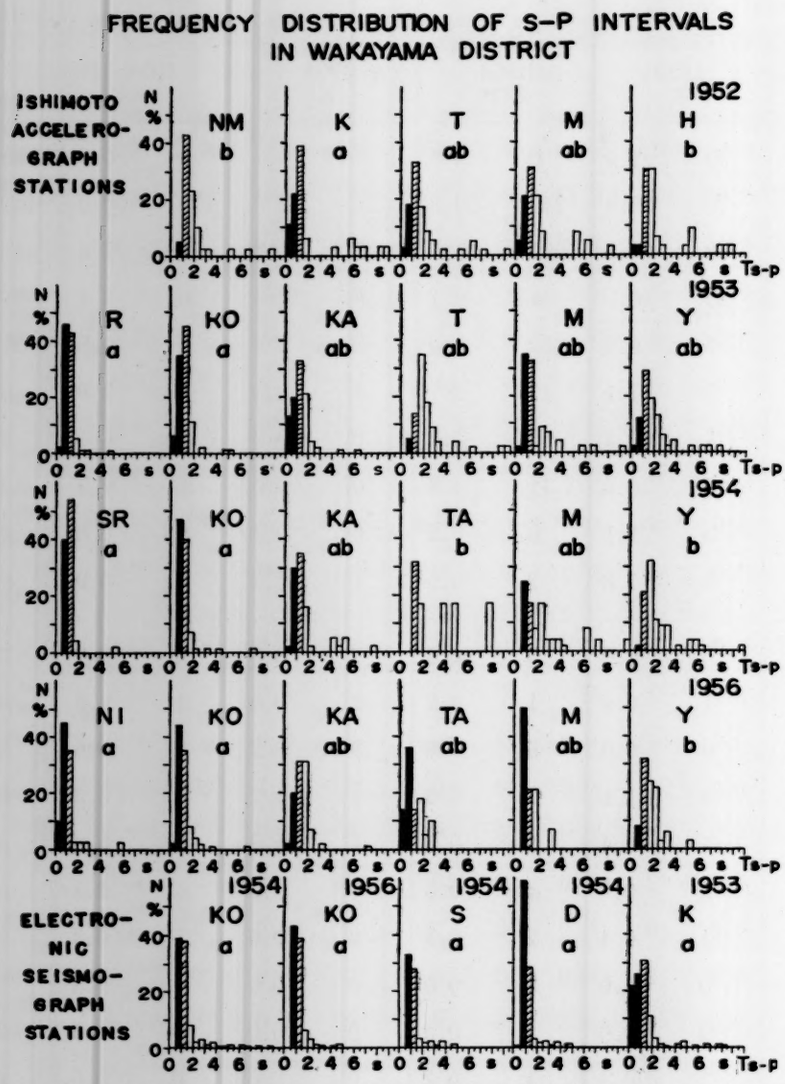


Fig. 4. Frequency distributions of $S$-$P$ intervals observed at the stations in respective years.
Filled histogram—$t_{S-P}<1.0$s. Hatched histogram—$t_{S-P}=1.0$–$1.5$s.
Blanck histogram—$t_{S-P}\geq 1.5$s.

a-タイプには K, R, SR, NI, KO, D, S, b-タイプには NM, H, Y (1953 年は 0.5～1.0sec が若干おおく ab-タイプにちかい), そして ab-タイプには T, TA, M, KA が属する. ただし TA (1954) は観測数がすくないのであやしい.

初期微動時間の最小値をしれば, それに一定数 (大森常数) をかけた数値にひとしい距離よりその観測点にちかい地殻内の部分に発生した地震はないことになる. 観測点を中心とするこのような半球状の部分を各観測点を中心としてえがき, その包絡面をつくるならば, この曲面は, その地域において地震の発生の期待しうる地殻部分と地震の発生のみら

れなかつた無地震表層の境界面となるので，これは地殻の地震活動度を表現するひとつの方法ということができる．このようなかんがえから，各点の最小初期微動時間をしらべてみる．偶然誤差をさけるために初期微動時間をよみとりえた総地震数の 10% だけの個数を，最小の $t_{S-P}$ から順次とつて，その算術平均をつくり，$\bar{\tau}_m$ として，Table 9 に附記した．この数値はほぼ a–タイプで 0.4～0.6 sec，b–タイプで 0.8～1.0sec，ab–タイプで 0.6～0.8sec 程度になつている．そこで，この地域で海南附近をとおる南北および東西両断面について，この数値をもとに，同一観測点は各年の平均値をとつてつくつた無地震表層底面すなわち地震発生域上面をしめしたものが Fig. 5 である．ただし Fig. 5 をつくるには近接観測点については平均値をつくり，これをもちいた．距離係数としては別に報告する[13]ようにこの地域の平均値として 6.8 km/sec が適当であることがわかつてるので，これをもちいた．

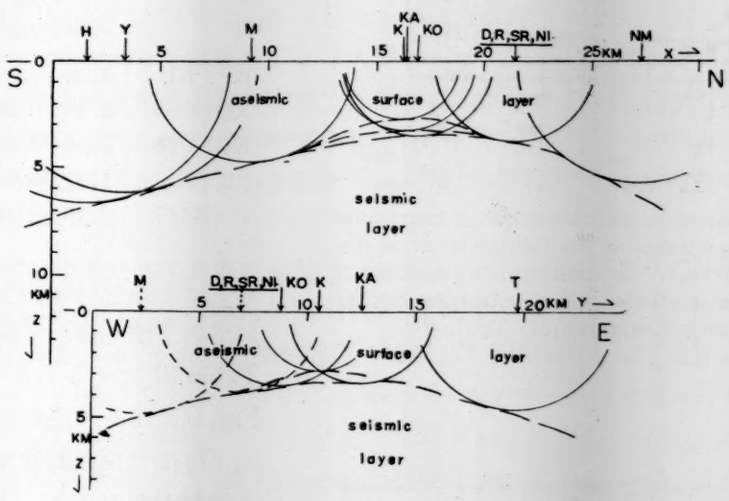


Fig. 5. Schematic profiles showing seismicity near Wakayama. Circles are 10% minimum *S–P* interval semi-spheres. Brocken lines are the sections of border surface enveloping aseismic upper layer.

**5·3 最大記録振巾**　一点で観測された地震動の最大記録振巾の頻度分布はいわゆる石本一飯田の関係[14]にしたがうといわれている．この臨時観測でえられた地震数は石本式加速度計では非常にすくないため，各回ごとにこれを検討することは適当でないので，同一地点またはごく近接した地点でおこなわれた観測は各回のものを通算したものについてしらべてみた．また電子地震計で相当多数の記録がえられたところについてもしらべてみた．それらの結果をまとめたものが Fig. 6 である．

石本一飯田の式の係数はその最小振巾区割と1区割内地震数が0となつた振巾以上の区

13) S. MIYAMURA, Read at the 396th Monthly Meeting of Earthq. Res. Inst., June, 1959.
14) M. ISHIMOTO *et* K. IIDA, "Observations sur les séismes enregistrés par le microsismographe construit dernièrement." *Bull. Earthq. Res. Inst.*, **17** (1939), 443–478. K. IIDA, *ibid.*, **17** (1939), 741–782, **18** (1940), 575–674.

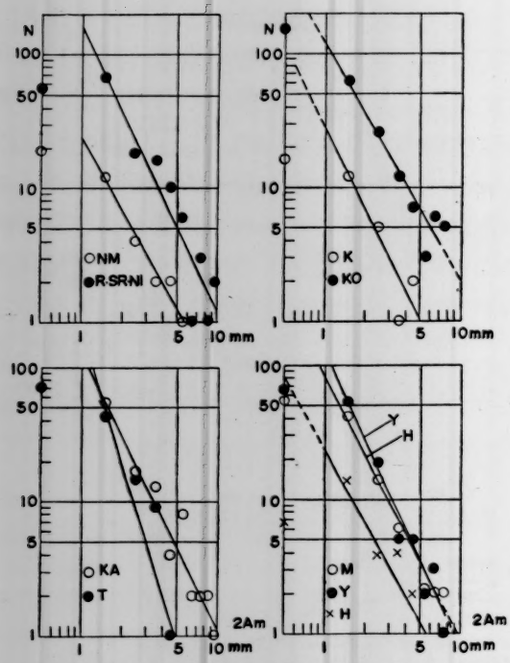


Fig. 6 a. Frequency distributions of maximum trace amplitudes at the Ishimoto accelerograph stations. Ishimoto-Iida's formulae at respective stations are determined by the least squares methods. (cf. Table 10)

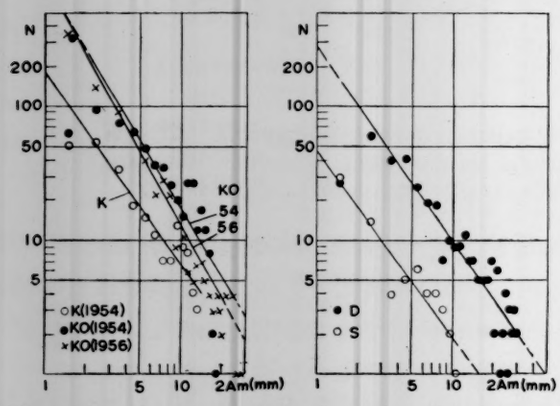


Fig. 6 b. Frequency distributions of maximum trace amplitudes at the electronic seismograph stations. Ishimoto-Iida's formulae at respective stations are determined by the least squares methods. (cf. Table 10)

Table 10. Coefficients of Ishimoto-Iida's formula $N=kA^{-m}$.

| Station | log $k$ | $m$ |
|---|---|---|
| NM | 1.36±0.15 | 0.80±0.51 |
| R, SR, NI | 2.20±0.16 | 2.10±0.51 |
| KO | 2.05±0.19 | 1.73±0.46 |
| K | 1.41±0.49 | 2.01±2.15 |
| KA | 2.11±0.16 | 2.05±0.31 |
| T, TA | 2.30±0.83 | 3.1 ±3.7 |
| M | 1.93±0.11 | 1.99±0.27 |
| Y | 2.12±0.17 | 2.31±0.42 |
| H | 1.39±0.25 | 1.63±0.99 |
| $K^E$ ('53) | 2.26±0.19 | 1.43±0.24 |
| $KO^E$ ('54) | 2.90±0.28 | 1.69±0.28 |
| $KO^E$ ('56) | 2.91±0.68 | 1.79±0.14 |
| S ('54) | 1.67±0.22 | 1.41±0.39 |
| D ('54) | 2.46±0.10 | 1.46±0.08 |

画とはとらないという通常もちいられてる方法で最小自乗法できめた. Table 10 にえられた係数をしめす. Fig. 6 にはその直線をしめした. 動木 (T) は初期微動頻度型に年度による変動があること, 1954 年のように有効観測日数のすくない年度があることからみて, 誤差がおおきいのはやむをえない. 1952 年の海南 (K) もやや観測精度がおちていたことがあらわれてるとおもわれる.

## 6. 考 察

上記臨時観測の結果については, 現在なお解析をすすめているから, 詳細の議論はのちの機会にゆずりたいが, 前節でえた結果から推定できる若干の事項について簡単に言及しておく.

紀伊半島局地地震のもつとも活溌な中心地域は海草有田両郡の海岸地帯であるが, 特に和歌山市, 海南市附近 (R, SR, NI, KO, K, D) は, もつとも地震発生数がおおく, しかも

震源は地表面から 3～4 km のところにはじまり，数 km 程度のものが大多数である (a–タイプ)．この地域の北方和泉砂岩地域の中松江や，南方の湯浅，広方面には，そのような極端にあさい地震はすくなく，全般的にややふかい地震 (10 km ca.) がふえる (b–タイプ)．これらの事情は Fig. 4 でもよくうかがうことができた．海岸からはなれた，海南市東方の動木では，1952 年にはやや活動が活潑で，ちかい（あさい？）地震もみられたが，1953年以後は海南高校(海南市東端)，箕島(長瀞変成帯南端) とともに ab–タイプになり，地震活動も a–タイプ地域にくらべ低調になつた．上記 a–タイプ地域は，かつて第1期の活動期に今村明恒[15]が研究した名草地震群乃至和歌浦湾地震群の震央域に対応するもので，水準測量による地殻の局部的相対隆起とよく一致していたが，最近の水準再測の結果[16]によると今回も同様の関係をしめしているようである．

よくしられているように，筑波山などでは初期微動時間4秒以下の地震はまつたくないといつてよいが[17]，この地方では逆に4秒以上の地震は非常にまれであつて，おなじく活潑な地震地域でありながら，関東地方とは大変ちがつた地震地域であることがわかる．このような極浅発地震は波動の減衰も顕著であつて，和歌山において震度Ⅱの地震で他の測候所でどこでも験測されないこともめずらしくない．したがつてその震源決定ができないだけでなく，同程度の地震がなお多数紀伊半島各地で発生しているものをのがしているおそれも充分あるといえる．

初期微動時間の頻度分布は従来の余震観測結果にしばしば報告されているが，それらのタイプをみるに，最近の例では今市地震 (1949, XII, 26)[18]のもので今市，西大芦が ab–タイプ，舟生，鹿沼，日光が b–タイプ，福井地震 (1948, VI, 28)[19] のもので塩屋，三国，丸岡が ab–タイプ，イブリ橋，大聖寺，清水，山中が b–タイプ，鳥取地震 (1943, IX, 10)[20] で鳥取は a–タイプにちかい ab–タイプ，倉吉，鹿野は ab–タイプ，青谷は b–タイプにちかい ab–タイプ，加茂 b–タイプとなつていて，明確な a– タイプはみいだせない．すなわちこれらとくらべるとき a–タイプ $S$–$P$ 時間頻度分布をしめす和歌山附近の地震はこれら大地震の余震群よりさらに局所的な浅発地震群であるということができる．$S$–$P$ 時間 a–タイプのモードを 0.5～1.0 sec として $k = 6.8$ km/s とすれば，もつともふかく直下としても 3～7 km のふかさに震源が分布することになる．

地表から数 km といえば，地質学的にみて当然その対象となる岩石があり，構造がある部分であつて，関東平野のおおくの地震のような地殻下地震が大構造との関連で考察さ

15) A. IMAMURA *et al.* "The Earthquake Swarms of Nagusa and Vicinity." *Bull. Earthq. Res. Inst.*, **10** (1932), 636-648.
16) S. MIYAMURA and A. OKADA, Read at the 311th Monthly Meeting of Earthq. Res. Inst., May 25, 1954.
17) S. MIYAMURA, "Minor Shocks Observed at Mt. Tukuba," Zisin, Ser. ii, **9** (1957), 236.
18) Earthq. Res. Inst., "Observations of After-shocks carried out in Imaichi District, Tochigi Prefecture," *Bull. Earthq. Res. Inst.*, **28** (1951), 389.
19) H. TSUYA, "The Fukui Earthquake of June 28, 1948. Chapter III. Aftershocks." Compiled by S. OMOTE. p. 44.
20) S. OMOTE, "Aftershocks that accompanied the Tottori Earthquake of Sept. 19, 1943," *Bull. Earthq. Res. Inst.*, **33** (1955), p. 646.

れなくてはならないのに対して．普通の意味での地質構造と対比してかんがえうる地震であるという点，きわめて興味あるものとおもわれる．地質時代の構造運動の継承，反転，新生と最近の構造運動との関連を西南日本外帯全帯にわたつてしらべ，その部分部分に発生している浅発地震（和歌山以外に四国の劒山附近，渥美湾，豊川附近，大井川流域などの地震活動がしられているが，いづれも詳細にはしらべられてない）の活動を考察することは，この地帯の現在における構造地質学的位置と地殻上層地震の地質的意義とを明確にするための第一歩であり，この点に特に紀伊半島局地地震研究の目標をおきたいのである．

## 7. 謝　　辞

各回の観測は Table 2 にしるしたように，耐久高校教諭新屋兼次郎先生はじめ，今村久（海南二中），新谷垣内正巳（大成高校），西口憲章（海南高校），小川恵三（星林高校），田中実蔵（箕島中学）の諸先生およびこれらの学校の地学クラブその他の有志生徒諸君の熱心な協力によりなされた．また通信線引込工事，計器輸送，観測保守等に関し，関西電力株式会社和歌山支店および管下各変電所，琴浦火力発電所の各位の厚意ある御援助をうけた．和歌山県，大阪管区気象台，および関西電力株式会社工務部からは今回の観測実施について全面的後援をえた．また海南市，和歌山市，和歌山県経営者協会，海南市商工会議所，朝日生命保険相互会社和歌山支社，和歌山電気軌道株式会社，野上電気鉄道株式会社，朝日新聞和歌山支局等からも各種の便宜をあたえられた．そのほかにも和歌山県の公私の多数から種々の応援をうけた．これらについて，ここにこころから感謝の辞をのべたい．

観測計器の借用をゆるされた気象台井上地震課長，本所萩原教授，表助教授の厚意に深謝する．観測点の位置決定をされた岡田惇氏，無線地震計の試験を応援された後藤健一氏，鈴木善吉氏をはじめ，つねにこれら観測の準備に協力された実川技官以下本所技術部の各位に感謝する．また本研究において終始協力をえた同僚堀実，辻浦賢，松本英照の三氏には特に深甚の謝意を表する．おわりに，長期にわたり著者に対しあたえられた那須所長のかわらざる厚意と激励とに謝意を表する．

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## *38. Local Earthquakes in Kii Peninsula, Central Japan. Part III. Temporary Seismological Network in the Neighbourhood of Wakayama.*

By Setumi MIYAMURA,
Earthquake Research Institute.

According to the instrumental observations[1] and intensity investigations[2] already reported, current seismic activity in Kii Peninsula was inferred to be concentrated in the littoral part between Wakayama and Gobo, and the depth of earthquake origins to

be very shallow. The author intended to locate them as accurately as possible, in order to search any geological implications of such supra-crustal seismicity.

In the autumns of 1952 to 1954 we operated temporary seismological networks in the neighbourhood of Wakayama and the 4th expedition was supplemented in April, 1956. General schedule of the 4 expeditions is given in Table 1, and several items of each network including the names of the observers are tabulated in Table 2. Table 3 lists the coordinates of the stations together with their geologic foundations. Fig. 1 illustrates the locations of those stations and the geology of the district.

Standard stations installed at 5 or 6 places in the district were equipped with 3-component Ishimoto accelerographs and their calibrated instrumental constants are tabulated in Table 4. As the writer with M. Hori[8] reported, 5% accuracy of uniformity in the constants used could not be attained easily. As recorders long drums like that adopted previously by the author with T. Akima[11] in the aftershock observation of Imaiti Earthquake, 1949, at Hunyu, were again used, replacing their driving motors with A.C. Wallen motors instead of D.C. motors. Rotating them in the speed of 2.5 minutes per revolution and renewing the recording papers two times a day, we were able to get a fairly rapid paper speed of about 4 mm/sec. Time marks were given in every second from one common standard clock directly on the pendulums by a divice shown in Fig. 2. In 1952 we used the standard time signals from Tokyo Astronomical Observatory through the short wave radio, JJY (4 Mc/s), receiving them separately at each station. Merits of the reception of JJY were not satisfactory as shown in Fig. 3, and we intended to get a more stable method giving time marks from a common clock. For this purposes line carrier telerecording chronograph, LTC, was developed by the writer with M. Tsujiura[3] and since the 2nd expedition the LTC system was introduced. In this case the standard chronometer at the transmitting station was, of course, checked by the standard time of JJY.

As expected by the reconnaissance observations[1] several tens of earthquakes were recorded at the temporary stations with Ishimoto accelerographs, but about 60% of them were recorded only at a single station. Only 12% were recorded at more than 4 stations which is the necessary condition in locating the hypocenter by $S$-$P$ method. Namely, our standard station network was too sparse, or the instruments used were not sensitive enough to cover the seismic area concerned. Consequently, we can only locate the hypocenters of comparatively deep and probably larger earthquakes by our seismological networks and very shallow, small ones cannot be located, as they are recorded only at one or two stations. On the other hand, seismic activities of the district seemed to decrease in 1954 especially in magnitude. Thus we developed an electronic seismograph, having a sensitivity as high as that used then in explosion seismology. It was used at Kainan (K) in 1953 and at Kotono-ura (KO) in 1954 and 1956, but we could not increase the number of station by entrusting it to an appropriate new observer. Above all, there are many inconveniences to install new stations, linked with the private telephone lines of Kansai Electric Co. Ltd. enabling the time mark of LTC system and to find reliable observers, to whom we entrust the keeping of our instruments. Thus the line and radio telerecording seismographs, abbreviated as LTS and RTS respectively, were designed and constructed[4,5]. Practical use was tested in 1954 and 1956, but here we do not touch upon anymore in detail.

Determination of geographical coordinates of the stations was executed by A. Okada, Techn. Div. of our Institute, connecting the stations geodetically to certain field objects, which could be fixed on the air photographs of Geographical Survey Institute, Ministry of Construction, and the accuracy was inferred to be nearly $\pm 10$ m.

Time accuracy of the observations was assumed to be as high as 0.02s, seeing from the adopted recording and time marking systems. As shown in Table 6 the lengths of a second on the seismograms have the dispersions of about 1~7%, and we can safely assure the time of later phase, e. g. that of $S$ from the time marks before $P$ within $\pm 0.05$s, neglecting the uncertainties in phase identification.

Having nearly equal sensitivity instruments, numbers of earthquakes recorded at the standard stations given in Table 7 a are said to be a measure of seismicity in the region in respective period of the expeditions. As there were no remarkable changes during the 4 periods in all stations, we can sum up the numbers of the same or very near stations in different periods and put them also in the Table 7 a. The most active seismicity was again indicated in Wakayama (R, RS, NI, KO) and Kainan (K, KA). Other stations in the bordering area follow them in seismicity. Results of electronic instruments in Table 7 b cannot be compared to see the seismicity, for the sensitivities adopted were different in each other. Table 8 lists the details of items shown in Table 7 a. As stated before, only very limited numbers were recorded at the enough numbers of stations to determine the origins by $P$ or $S$-$P$ methods.

Frequency distributions of $S$-$P$ intervals observed are listed in Table 9 and illustrated in Fig. 4. In Table 9, percentage numbers of $S$-$P$ intervals occupying more than 10% of all identified shocks at a station are enclosed by rectangles in full lines and those more than 5% by rectangles in dotted lines. They clearly show that there are 3 types of $S$-$P$ frequency distribution (See Fig. 4): at some stations greater part of $S$-$P$ intervals is smaller than 1.0s, while almost none is found at longer than 2.0s. (a-type) At other stations $S$-$P$ intervals smaller than 1.0s can hardly be found and greater part of them is greater than 1.0s, inclusive of many being greater than 2.0s. (b-type) And, of course, there are stations called to the intermediate type, with a broad distribution between 0.5~2.0s and with some greater than 2.0s. (ab-type) These 3 types represent the general tendency of space distribution of earthquakes around the stations. All a-type stations (IA stations: 1952-K, 1953-R, KO, KA, 1954-SR, KO, 1956-NI, KO; Electronic and telerecording stations: 1953-K, 1954-KO, S, D, 1956-KO) are distributed near Wakayama and Kainan, and coincide with the highest seismicity. ab-type and b-type stations are situated around the a-type area and characterized with rather low seismicity. Frequency distributions of $S$-$P$ intervals obtained in the aftershock observations of the recent Japanese earthquakes[18~20] indicate that most of them were ab- or b-type, and comparing with them, the Wakayama earthquake swarms are said to have more local and shallower origins.

The author proposed a concept of an aseismic surface layer which is simply defined as follows and will be a rough but useful measure of seismicity. If the minimum $S$-$P$ interval observed at a certain station in a limited period is $\tau_m$, we can construct a hemi-sphere in the crust, its center being the station and its radius being $k\tau_m$ km, where $k$ is Omori's distance coefficient or the fictitious velocity of $S$-$P$ wave in km/s. We can safely ascertain that we found no earthquake origin within this hemi-sphere during the period concerned. Constructing such hemi-spheres at all stations covering an area, we can obtain an enveloping surface of the hemi-spheres, boundering the upper aseismic and lower seismic layers in the earth's crust beneath the area. Considering the rare but inevitable errors in $S$-$P$ interval identification and the statistical nature of geophysical inferences deduced from the observations in limited times, we should rather take the following averaged value $\bar{\tau}_m$, instead of a single $\tau_m$ value. When the number of total identified $S$-$P$ intervals is N, mean value of $0.1 \times$ N smallest $S$-$P$ intervals is calculated and defined as $\bar{\tau}_m$, which we call 10% minimum $S$-$P$. In Table 8, $\bar{\tau}_m$ values for every

station were given, and basing these values we construct an envelope surface between the upper and lower layers of opposite nature in seismicity. In the construction we take mean values of $\bar{\tau}_m$ at a station for different years and of very near stations for different years, and $k = 6.8$ km/s calculated as a mean in the district[13]. In Fig. 5 show the N–S and E–W vertical sections through Kainan and vicinity indicating the aseismic surface layer under the area. It clearly shows that the seismic activity comes up very near the surface as shallow as a few kilometers in the neighbourhood of Kainan and Wakayama. Consider that no earthquake with $S$–$P$ smaller than 4s is observed at Tukuba[17], which lies in the center of Kwanto District, the most active seismic region of Japan!

Frequency distributions of recorded maximum amplitudes were investigated and, generally speaking, so-called Ishimoto-Iida's formula[14] hold good in every case. Results are shown in Table 10 and Fig. 6.

There remain many items to be considered including the seismometrical determination of the location of earthquake origins, but we will treat them in the following papers.

地震研究所彙報
第37号 (1959) 637-647頁

# 39. 南九州の“しらす”の粒度組成

地震研究所 村井 勇
津屋弘達

(昭和34年9月22日発表——昭和34年9月30日受理)

## I まえがき

筆者等は，先に，浅間火山南側中腹より山麓部一帯にわたつて分布する軽石質の火山砕屑堆積物を調査し，その粒度組成の特徴が，*nuée ardente* の産物と考えられる Crater Lake 地域の “Older Pumice” と類似し，また分布の全範囲にわたつて粒度の規則的変化が見られず，分布の限界が判然としていることなどから見て，pyroclastic flow の堆積物と考えられると論じた[1]．この際，pyroclastic flow の他の例として，種子田定勝による南九州の“しらす”の機械分析の資料[2]を取り上げて比較したが，この資料は機械分析が全ての粒度にわたつて完全に行われていなかつたため，十分な検討ができなかつた．筆者等は今回，機会を得て“しらす”の試料を採集し，その機械分析を行うことができたので，ここにその結果を報告する．

報告に先だつて，現地における調査にあたり種々御便宜をとりはからつていただいた，鹿児島県庁観光課村岡逸雄氏と鹿児島大学助教授露木利貞氏にお礼を申し上げる．また，地震研究所小諸支所の細谷与七氏には，機械分析の一部を担当していただき，挿図の浄書をお願いした．

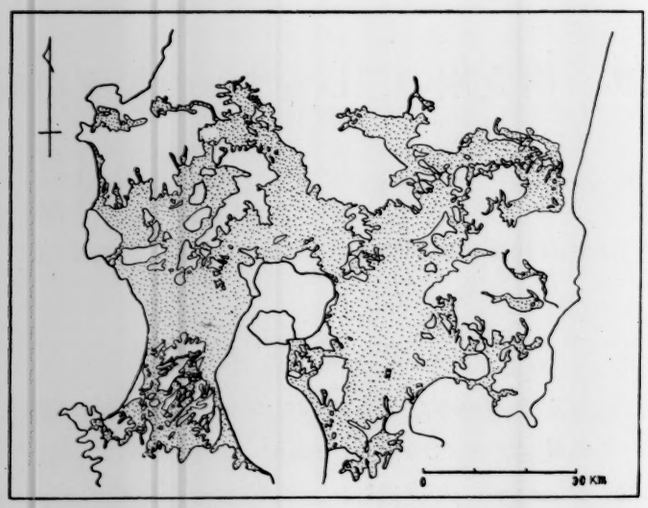
## II いわゆる“しらす”について

南九州の“しらす”については，すでに以前から多くの論文がある[3]，鹿児島県の大半および宮崎南部にわたつて非常に広い分布を示し，鹿児島湾北部を中心として，西は川内市西方海岸，北は大口町および小林市，東は宮崎市にまでひろがり，南は薩摩半島および大隅半島の南端にまでおよんでいる(第1図および第2図参照)．“しらす”は多くの場合“灰石(はいいし)”とあい伴つて分布している．“灰石”は“しらす”の熔結した部分と解釈される．

1) 津屋弘達・村井 勇・細谷与七 「小諸附近に分布する浅間火山軽石の粒度組成」 地震研究所彙報 **36** (1958), 413～431.

2) Sadakatu TANEDA, “Geological and Petrological Studies on the Shirasu in South Kyushu, Japan, Part I. Preliminary note”, *Memoirs of the Faculty of Sci., Kyushu Univ. Series D. geol.*, **4** (1954), 167～177.

3) 松本唯一 「姶良火山について」 地理学評論 **9** (1933), 614～626.
小田亮平 「鹿児島市外吉野台の地質」 地質学雑誌 **24** (1917), 233～244.
山口鎌次 「北部鹿児島湾の周縁地域特に吉野台の地質について」 地質学雑誌 **44** (1937), 222～225.




第1図 姶良カルデラの“しらす”の分布図 (松本唯一による)

層厚は非常に厚く，地域的に変化が著しいが，大体 100 m 前後 (50～150 m) である．“しらす”は洪積層もしくは第三紀層と見られる水成岩層，第三紀層，および第三紀火成岩類を不整合におおい，上部を軽石・火山灰等の降下性火砕堆積物によつておおわれている．個々の地域における“しらす”の内部の細かい層序の調査はまだ十分に行われていず，また層内の各部分の横方向のつながりも明らかにされていないが，その主体をなすものは姶良カルデラの成立に関係があり，おそらくカルデラ形成の直前に噴出した火山砕屑流の堆積物であろうとされている．湊正雄と勝井義雄によれば，鹿児島市北方の地域においては，姶良カルデラ形成に関係があると見られる“しらす”(姶良熔結凝灰岩と呼んでいる) は3層に分れるという．上部は無層理の軟弱粗鬆の部分であり，中部は熔結がいちぢるしく，柱状節理が発達している．下部は薄い数枚の層からなり，おそらく大規模な中・上部の“しらす”の噴出の前に行われた先駆的活動によるものと見られている[1]．なお，“しらす”のうち大隅半島南部および薩摩半島南端に分布するものは，松本唯一により阿多カルデラに関係あるものとされている[2]．また，湊正雄と勝井義雄によれば，“しらす”および“灰石”と呼ばれてきたものの中には，前記の姶良熔結凝灰岩のほかに，さらに古期の層準を占るものもあるという．

以上のように，北部鹿児島湾周縁地域の“しらす”は，姶良カルデラに関係ある火山噴出物で，おそらく火砕流の状態で噴出したと考えられているが，すべて無層理の分級の悪い堆積物であつて，外観は筆者等が先に報告した小諸附近に分布する浅間火山の軽石層ときわめてよく類似している．

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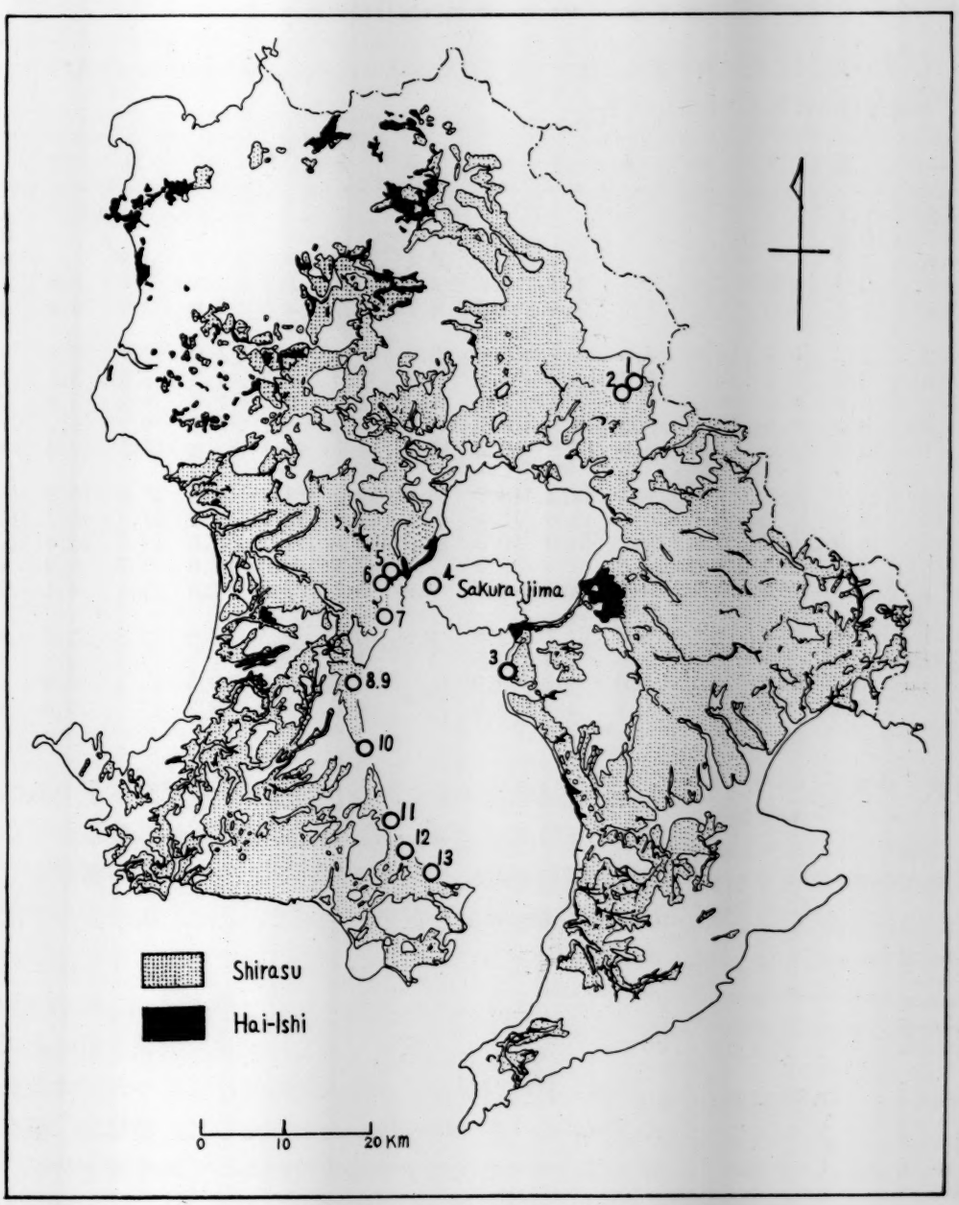
1) 湊 正雄・勝井義雄 「鹿児島県竜水・磯附近の地質」地質学雑誌 **63** (1957) 300～307.

2) Tadaichi MATSUMOTO, “The Four Gigantic Caldera Volcanoes of Kyushu”, *Jap. J. Geol. Geogr.*, **19** (1943), sp. no., 1～57.




第2図　試料の採集地点を示す図
“しらす”および“はいいし”の分布は種子田定勝 (1953) による.

## III　試料の採取と機械分析

筆者等は，鹿児島市周辺の地域で，姶良カルデラの“しらす”から数個の試料を採集して，機械分析を行つた．試料の採集地点は第2図に示してある．また，個々の試料を得た層準は第3表の備考欄に記してある．

第1表 “しらす”の機械分析の結果

1, 2～12, 13は試料の番号，欄内の数字は各区間の占める重量%を示す．各試料の採集地点は第2図に示してある．

| φ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ～−8 | 1.1 | | | | | | | | | | | | |
| −8～−7 | 0.9 | | | | | | | | | | | | 0.9 |
| −7～−6 | 1.2 | | 1.1 | | | 1.1 | 0.4 | | 0.2 | | 0.3 | | 0.4 |
| −6～−5 | 0.9 | 2.0 | 2.4 | | 1.2 | 2.4 | 2.4 | | 1.5 | | 1.8 | 2.0 | 1.5 |
| −5～−4 | 1.2 | 6.0 | 5.2 | 1.1 | 1.4 | 5.8 | 6.7 | | 4.8 | 1.0 | 2.2 | 5.4 | 3.7 |
| −4～−3 | 2.7 | 6.5 | 11.9 | 5.6 | 1.5 | 5.4 | 5.7 | | 8.2 | 1.0 | 2.7 | 2.9 | 4.3 |
| −3～−2 | 5.0 | 7.2 | 12.3 | 11.3 | 1.2 | 4.5 | 4.6 | 1.0 | 9.3 | 1.3 | 3.3 | 3.1 | 3.9 |
| −2～−1 | 5.1 | 8.2 | 11.9 | 7.8 | 5.2 | 5.8 | 5.2 | 1.7 | 7.0 | 2.4 | 4.3 | 2.9 | 3.3 |
| −1～ 0 | 8.2 | 7.1 | 13.0 | 2.6 | 14.0 | 10.1 | 8.9 | 4.2 | 2.1 | 5.9 | 9.3 | 7.1 | 7.7 |
| 0～ 1 | 13.0 | 13.3 | 15.3 | 4.9 | 17.8 | 13.2 | 13.4 | 14.1 | 8.7 | 13.8 | 15.5 | 12.6 | 14.8 |
| 1～ 2 | 15.7 | 12.9 | 12.9 | 7.7 | 14.3 | 13.7 | 14.0 | 18.8 | 13.5 | 18.9 | 17.6 | 16.3 | 15.1 |
| 2～ 3 | 13.8 | 11.8 | 6.1 | 10.3 | 12.6 | 12.4 | 12.5 | 17.1 | 12.9 | 19.9 | 17.7 | 15.7 | 14.7 |
| 3～ 4 | 11.9 | 10.0 | 2.2 | 12.2 | 10.6 | 10.3 | 10.6 | 12.3 | 11.2 | 15.8 | 12.5 | 13.6 | 12.4 |
| 4～ 5 | 7.2 | 4.9 | 1.0 | 12.5 | 7.3 | 5.3 | 7.3 | 7.9 | 6.8 | 8.6 | 5.7 | 8.9 | 7.3 |
| 5～ 6 | 4.8 | 2.5 | 1.0 | 9.0 | 4.4 | 3.0 | 2.9 | 5.5 | 3.2 | 4.3 | 2.1 | 4.1 | 2.8 |
| 6～ 7 | 1.6 | 1.7 | 0.5 | 5.5 | 3.7 | 2.6 | 2.3 | 4.1 | 2.5 | 2.5 | 2.3 | 2.7 | 2.1 |
| 7～ 8 | 0.3 | 1.4 | 0.4 | 2.8 | 1.6 | 0.5 | 1.1 | 3.3 | 2.9 | 1.1 | 1.0 | 0.9 | 0.8 |
| 8～ 9 | 0.3 | 0.3 | 0.2 | 1.6 | 0.2 | 0.9 | } 2.0 | 1.7 | 1.3 | 0.3 | } 1.7 | 0.9 | 0.1 |
| 9～ | 5.1 | 4.2 | 2.6 | 5.1 | 3.0 | 3.0 | } | 8.3 | 3.9 | 3.2 | } | 0.9 | 4.2 |

第2表 阿蘇火山の“はいいし”の粒度組成

| | 14 | 15 |
|---|---|---|
| ～−8 | | |
| −8～−7 | | |
| −7～−6 | | 0.3 |
| −6～−5 | | 0.5 |
| −5～−4 | | 0.9 |
| −4～−3 | 0.8 | 1.3 |
| −3～−2 | 1.7 | 1.2 |
| −2～−1 | 2.1 | 1.6 |
| −1～ 0 | 4.4 | 2.2 |
| 0～ 1 | 7.8 | 6.1 |
| 1～ 2 | 10.0 | 9.1 |
| 2～ 3 | 11.2 | 14.3 |
| 3～ 4 | 13.3 | 18.1 |
| 4～ 5 | 15.5 | 14.3 |
| 5～ 6 | 11.4 | 12.5 |
| 6～ 7 | 8.6 | 7.1 |
| 7～ 8 | 5.8 | 2.7 |
| 8～ 9 | 1.5 | 1.1 |
| 9～ 10 | } 5.9 | 0.8 |
| 10～ | } | 5.9 |

試料の採集はできるかぎり広範囲から行うべきであつたが調査日程等のことから鹿児島市周辺のみに限られてしまつた．試料の採取にあたつては，最も条件のよい露頭をえらんで，約1 kg程度を採集した．また別に，露頭面の写真をとり，試料の量が限られることのために生ずる粗粒部分の分析結果の誤差を補正する資料とした．採集した試料のうち50 gを保存用として残し，残りの全量を機械分析にあてた．

機械分析はつぎの3つの段階に分けて行つた．すなわち，まず試料のうち50～80 gをとりだして，傾瀉法，篩分け法およびピペット法により全粒度についての分析を行い，つぎに残りの試料全部を8メッシュ（径約2 mm）の篩の上で水洗いし，風乾したのち篩分けを行い，最後に写真によつて直径16 mm以上の粒子の分析を行つた（この方法については別の機会に詳しく説明することとし，ここでは省略する）．このようにして，少量の試料による全粒度の分析，8メッシュ以上の篩分け，直径16 mm以上の写真による分析の3段階を経た上で，得られた結果を整理して，全粒度の完全分析の結果とした．第1表に示したものは，こうして得られたも

第 3 表　粒度分布曲線の各パラメーターの値

| | $Md_\phi$ | $M_\phi$ | $Q'$ | $Q''$ | $\sigma_\phi$ | $\alpha_\phi$ | $\alpha_{2\phi}$ | $\beta_\phi$ | 備　考 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.67 | 1.515 | 1.79 | −0.022 | 2.875 | −0.053 | 0.288 | 1.295 | 中　部 |
| 2 | 0.98 | 0.55 | 2.30 | −0.243 | 3.32 | −0.129 | 0.170 | 0.808 | 中　部 |
| 3 | −0.57 | −0.78 | 1.85 | −0.227 | 2.60 | −0.080 | −0.209 | 0.759 | ? |
| 4 | 2.89 | 1.855 | 3.085 | −0.683 | 4.025 | −0.257 | 0.011 | 0.519 | ? |
| 5 | 1.52 | 1.965 | 1.745 | 0.257 | 2.535 | 0.175 | 0.333 | 0.808 | 上　部 |
| 6 | 1.13 | 0.60 | 2.02 | −0.108 | 3.30 | −0.160 | −0.022 | 0.750 | 中　部 |
| 7 | 1.20 | 0.56 | 2.04 | −0.156 | 3.39 | −0.188 | −0.148 | 0.585 | 中　部 |
| 8 | 2.57 | 3.50 | 1.715 | 0.437 | 2.82 | 0.329 | 0.888 | 0.923 | 下　部 |
| 9 | 1.67 | 0.85 | 2.71 | −0.597 | 3.73 | −0.206 | 0.085 | 0.659 | 下　部 |
| 10 | 2.29 | 2.37 | 1.32 | 0.151 | 2.04 | 0.039 | 0.250 | 0.975 | 下　部 |
| 11 | 1.62 | 1.435 | 1.47 | −0.108 | 2.185 | −0.084 | −0.221 | 1.226 | 中　部 |
| 12 | 1.77 | 1.575 | 1.66 | 0.048 | 2.645 | −0.073 | −0.364 | 0.998 | 中　部 |
| 13 | 1.63 | 1.27 | 1.70 | — | 2.87 | −0.125 | −0.094 | 1.000 | 中　部 |
| 14 | 3.92 | 3.77 | 1.93 | −0.155 | 2.85 | −0.025 | 0.228 | 0.905 | 臼杵市 |
| 15 | 3.68 | 3.695 | 1.59 | 0.108 | 2.475 | −0.006 | 0.492 | 1.545 | 人吉市 |

のである.

## IV　機械分析の結果

機械分析の結果は第 1 表に示した通りであるが，これをヒストグラムおよび累積和曲線で示せば第 3 図および第 4 図のようになる．つぎに，累積和曲線上で $\phi_5$, $\phi_{16}$, $\phi_{25}$, $\phi_{50}$, $\phi_{75}$, $\phi_{84}$, $\phi_{95}$（それぞれ 5%, 16%, 25%, 50%, 75%, 84%, 95%にあたる程度を $\phi$ スケールで表わしたもの，但し $\phi=-\log_2\xi$, $\xi$ は粒径を mm で表わしたもの）を読みとり，これらの値から粒度分布のパラメーターを計算する.

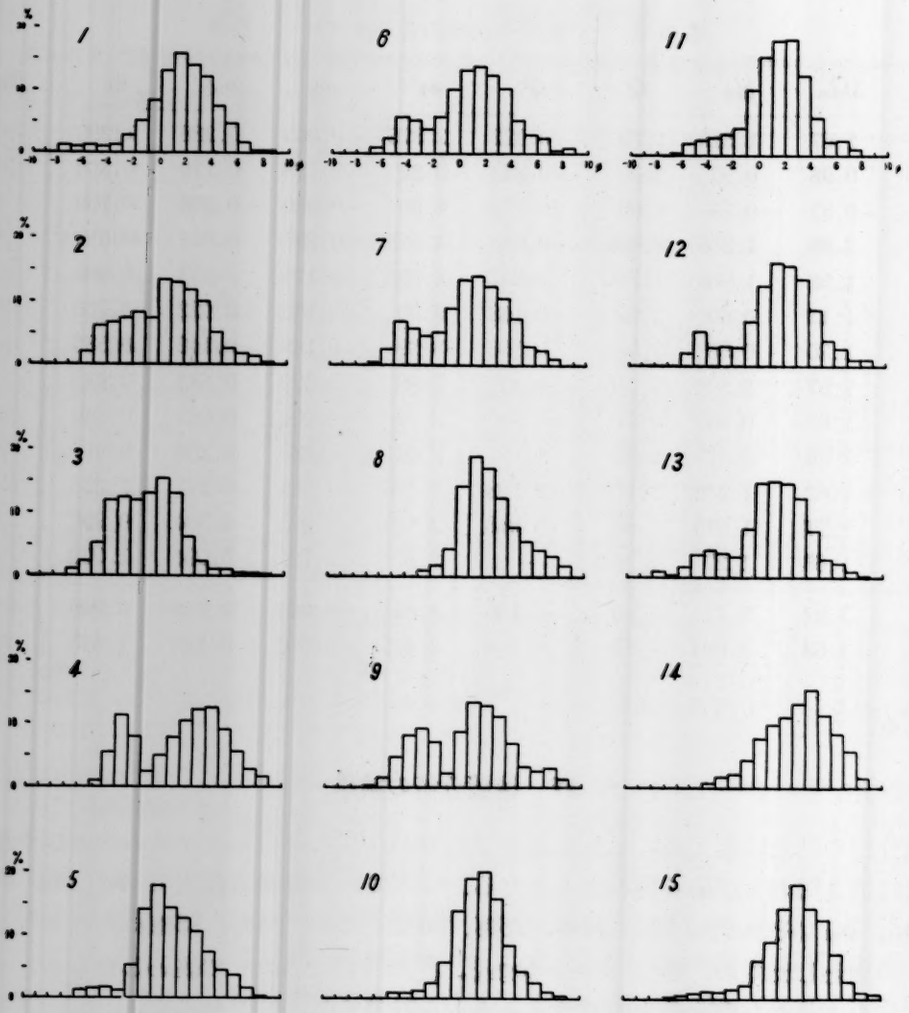
$$Md_\phi=\phi_{50},\quad M_\phi=(\phi_{16}+\phi_{84})/2,$$
$$Q'=(\phi_{75}-\phi_{25})/2,\quad Q''=(\phi_{75}+\phi_{25}-2\phi_{50})/Q',$$
$$\sigma_\phi=(\phi_{84}-\phi_{16})/2,\quad \alpha_\phi=(M_\phi-\phi_{50})/\sigma_\phi,$$
$$\alpha_{2\phi}=\frac{\frac{1}{2}(\phi_5+\phi_{95})-\phi_{50}}{\sigma_\phi},\quad \beta_\phi=\frac{\frac{1}{2}(\phi_{95}-\phi_5)-\sigma_\phi}{\sigma_\phi}$$

$Md_\phi$, $Q'$, $Q''$ は普通に統計学上用いられるパラメーター（中央値，および偏差，歪度の近似値）であり，$M_\phi$; $\sigma_\phi$; $\alpha_\phi$, $\alpha_{2\phi}$; $\beta_\phi$ は Inman, D. L. (1952) によるパラメーター（平均値，偏差，歪度，尖度の近似値）である．これらの値を第 3 表に示す.

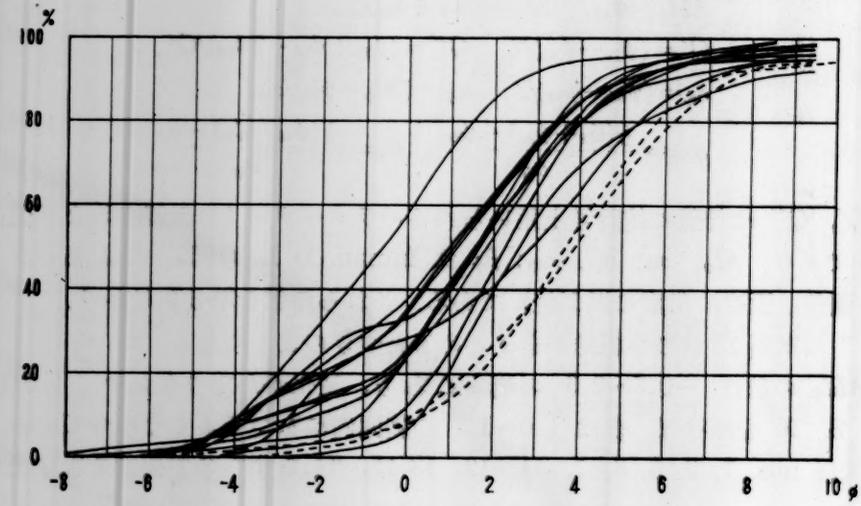
“しらす”の試料 13 個の分析結果をまとめるとつぎのようになる.

1)　$Md_\phi$ の値は −0.6～2.9 の範囲にあり，変化がかなり著しい．しかし，試料 nos. 4, 8, 10 を除けば，他は 1.0～1.7 の範囲内にあつてよくそろつている.

2)　試料 nos. 1, 2, 5, 6, 7, 11, 12, 13 は，“しらす”の主要部をなす上部および




第3図　粒度分布のヒストグラム　1，2～13：“しらす”，14，15：阿蘇火山“はいいし”




第4図　粒度分布の累積和曲線　実線：“しらす”，破線：阿蘇火山の “はいいし”

中部から採集した試料であるが，その粒度分布曲線はきわめてよく類似している．粒度にも差はほとんどない．全粒度のうち，粗粒部分（$\phi<-2$）は 5～20%を占め，また細粒部分（$\phi>2$）は 35～40%に達して，分級は相当に悪い．いずれの場合も $\phi=0$～2 に主モードを，$\phi=-3$～$-2$ 附近に副モードを示している．副モードは粗粒の軽石の部分を表わすもので，その表われかたは試料によつてかなりの差がある．

3) 試料 nos. 8, 9, 10 は下部“しらす”に相当すると見られる部分から採集したものであるが，粒度分布は上記の群に比していく分異なつている．no. 9 は粗粒部の副モードが著しく卓越しており，一方 no. 8, no. 10 では副モードが見られない．この3つの試料は分布曲線および $Md_\phi$ の値が上記の群といく分異なつているにもかかわらず，いずれも $\phi=1$～2 に主モードを持ち，この点では上記の群と異なるところはない．

4) 試料 no. 3 は $Md_\phi$ が $-0.57$ という値をとり，他の試料に比して粒度が著しく大きい．露頭面で見たところでは，堆積の際二次的作用の影響があつたと見られる様相を示し，一部に著しい成層が認められた．しかしこの試料の粒度分布は一見非常に特異のようであるが，$\phi=1$ 附近の主モードをやはり示しており，$\phi=-3$ 附近の副モードが非常に卓越したものと解釈することができる．

5) 試料 no. 4 は桜島袴腰より採集したもので，姶良カルデラ内部において採集した唯一の試料である．この試料では，主モードの位置が他の試料よりずれて $\phi=4$ 附近に表われ，$\phi=-2$ 附近の副モードが著しく卓越している．

6) $Q'$ の値は 1.5～3.1，また $\sigma_\phi$ の値は 2.0～5.0 で，全部の試料が分級はかなり悪い．これは粗粒部に副モードのあること，および粒度が粗粒部と細粒部の両端に向つて長く尾を引いていることのためである．

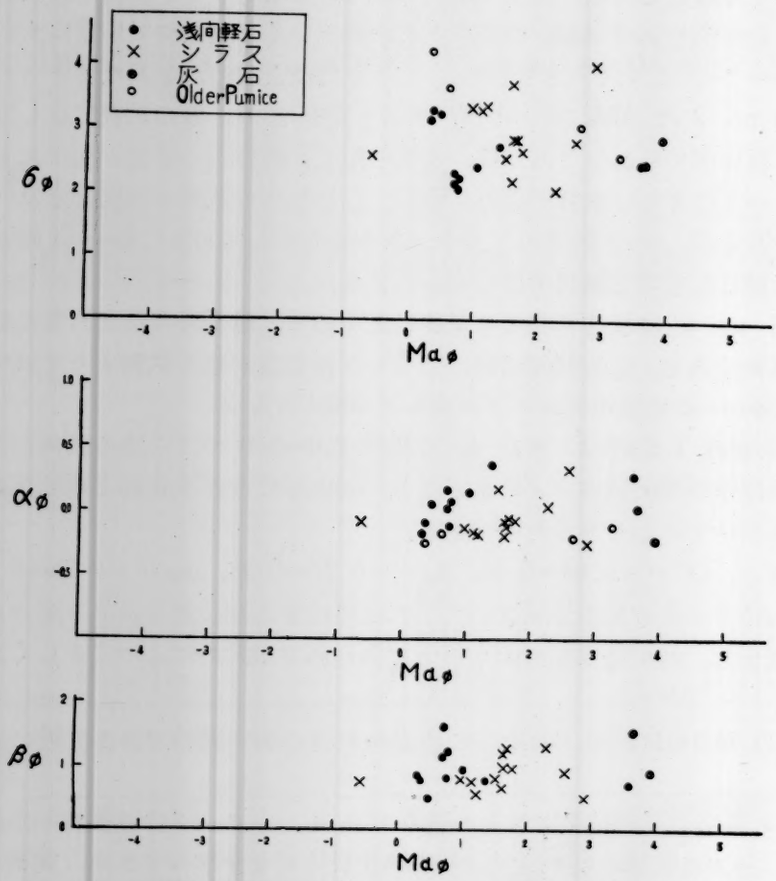
7) 歪度は，$Q''=-0.68$～$0.44$，$\alpha_\phi=-0.26$～$0.33$，$\alpha_{2\phi}=-0.36$～$0.89$ で，正と負の両方の場合があり変動が大きい．これは粗粒部と細粒部の占める割合が試料によつてかなり変動し，特に粗粒部の副モードの表われ方が試料によつて著しく異なるためである．

8) $\beta_\phi$ は 0.5～1.3 で，副モードの表われ方の弱い試料では1に近い値を示している．

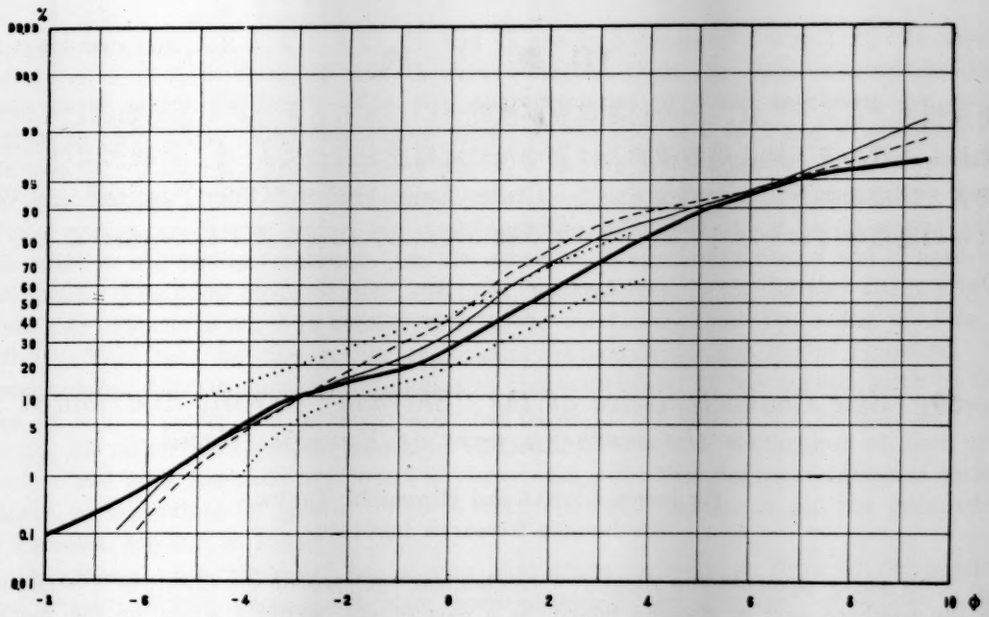
“しらす”の機械分析の結果は以上の通りである．主モードは結晶粒が主成分をなす部分にあたり，一方粗粒部の副モードは軽石が主成分をなす部分である．試料 no. 4 を除けば，他はいずれも主モード，副モードがほぼ同じ粒度のところに表われている，試料 nos. 3. 4. 9 は副モードが著しく卓越して，一見特異の様相を示しているが，それ以外の特徴は他の試料と共通している．結局，no. 4 のみが主モードの位置が他の試料に比して少し細粒の方にずれているという点で特に異なつているが，これは，鹿児島湾北部の輪廓を姶良カルデラの壁と見れば，no. 4 のみがそのカルデラ内の試料であるということと関係があるかもしれない．

## V 浅間火山の軽石との比較

南九州の“しらす”を，筆者等が先に調査した浅間火山の軽石と比較して見れば，両者が著しく類似した粒度分布を示すことが一見して知れる．$Md_\phi$ の値は,“しらす”が −0.6～2.9（主要試料は 1.0～1.7）であり，浅間火山の軽石が 0.3～1.5 であるのに較べて，“しらす”の方がいく分細粒である．分級の程度は両者とも全く同程度である（第5図参照）．浅間火山の軽石では $\sigma_\phi$=2.1～2.3，“しらす”は $\sigma_\phi$=2.0～4.0 で，いずれも $\sigma_\phi$ は2以上の値をとつている．これは，一般の降下性の軽石および火山灰では，$\sigma_\phi$ が大体 1～2 の範囲にあるのが普通であることと比較して，きわめて特徴的である．歪度は浅間火山の軽石も“しらす”も，いずれも正負両方の値をとり，特に負の値をとる場合が多いが，この点も，降下軽石では正の値をとることが普通であることと比較して，対照的である．“しらす”および浅間火山の軽石の以上のような粒度組成の特徴は，Crater Lake 地




第5図 $Md_\phi$ と $\sigma_\phi$，$\alpha_\phi$，$\beta_\phi$ との関係を示す図




第6図　確率紙上に描いた粒度分布の累積和曲線
太い実線：“しらす”の平均（nos. 3, 4, 8 を除く），細い実線：浅間火山軽石の平均，破線：箱根火山軽石の平均，点線：Older Pumice (MOORE. B.N. の sp. nos. 34, 53a).

域の “Older Pumice” や St. Vincent の glowing avalanche (*nuée ardente*) deposit の場合とよく類似している[1]．このことは粒度分布の累積和曲線を確率紙上に描けば明瞭に認められる（第6図）．なおこの第6図中には，参考のため箱根火山の軽石流堆積物の粒度分布の曲線も記入して見たが，上記のものと非常によく類似した曲線を示している．

筆者等は，“しらす”のほかに，阿蘇火山の“灰石”の試料を，大分県臼杵市および熊本県人吉市において2個採集し，機械分析を試みた．その結果は第2表に示してある．ヒストグラム，累積和曲線，パラメーターの値等は，“しらす”とともに第3，4，5図，第3表中に記入してある．阿蘇火山の“灰石”は阿蘇カルデラの形成に関係ある噴出物と見られ，“しらす”と同様火砕流の状態で噴出したと解釈されているものである．この“灰石”は，“しらす”に比して，更に細粒で，$Md_\phi$ は 3.92 および 3.68 であつた．モードは $\phi=3\sim5$ にあり，副モードは人吉市の試料（no. 15）において $\phi=-3$ 附近にわずかに認められるのみである．$\sigma_\phi$ は 2.85 および 2.475 で，いずれも2より大きい．$\alpha_\phi$ は負の値をとり，$\beta_\phi$ は 0.9 および 1.5 となつている．以上のように，ヒストグラムを見ても，累積和曲線によつても，またパラメーターの値からしても，阿蘇火山の“灰石”は，細粒であるという点以外は，南九州の“しらす”にきわめてよく類似している．

1) Bernard N. MOORE, “Deposits of Possible Nuée Ardente Origin in the Crater Lake Region, Oregon”, *Jour. Geol.*, **42** (1934), 358～375.
Richard L. Hay, “Formation of the Crystal-Rich Glowing Avalanche Deposits of St. Vincent, B.W.I.”, *Jonr. Geol.* **67** (1959), 540～562.

## VII 要 約

南九州の“しらす”は，その粒度組成が浅間火山の軽石ときわめてよく類似している．いずれも一般の降下性火砕堆積物とは異つた粒度組成を持つている．阿蘇火山の“灰石”も前者と同様の粒度組成を持つている．Crater Lake 地域の“Older Pumice”と同様に，これらの堆積物はおそらく火山砕屑流の状態で噴出し，山腹を流下して堆積したものであろう．

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## *39. Size Characteristics of the "Shirasu" deposit distributed in the southern part of Kyushu Island.*

By Isamu MURAI and Hiromichi TSUYA,
Earthquake Research Institute.

This paper presents the results of mechanical analyses of the "Shirasu" distributed in the southern part of Kyushu Island, as a part of the writer's study on the mechanical composition of pyroclastic deposits of several volcanoes in Japan. The "Shirasu", which means "white sand", is distributed widely in the volcanic district of South Kyushu, forming a vast tableland around the north part of Kagoshima Bay. It is very often accompanied with the underlying "Hai-ishi", which means "ash stone" and may be a welded part of the "Shirasu". The "Shirasu" consists mainly of volcanic ash and pumice, accompanied with some rock fragments. Its thickness varies greatly, usually being 50 to 150 meters. It shows no bedding in almost every case. (see Figs. 1 and 2)

Samples of about 1 kg weight of the "Shirasu" were collected in several localities for mechanical analyses. Mechanical analyses of all samples were carried out by means of sieving, decantation and pipette method. Besides, all the results of mechanical analyses obtained by such laboratory work were corrected for the coarser grain size by referring to the photographs of the outcrops, from which the specimens were picked up. Analyses have been made of 13 specimens of the "Shirasu", and 2 specimens of the "Hai-ishi" of Mt. Aso, which is considered as the similar deposits. The results of analyses are shown in Table 1, and Figs. 3, 4. The diameters of particles in millimeters $\xi$ are replaced here by $\phi$ as expressed $\phi=-\log_2 \xi$ for convenience. Approximate value of every sort of parameter of the size distribution, that is, mean $M\phi$, median $Md\phi$, deviation or sorting $Q$ and $\sigma\phi$, skewness $Q'$, $\alpha\phi$ and $\alpha_2\phi$, and kurtosis $\beta\phi$, in $\phi$ scale are obtained from the following relations.

$$M\phi=(\phi_{16}+\phi_{84})/2, \quad Md\phi=\phi_{50},$$
$$Q'=(\phi_{75}-\phi_{25})/2, \quad \sigma\phi=(\phi_{84}-\phi_{16})/2$$
$$Q''=(\phi_{75}+\phi_{25}-2\phi_{50})/Q'$$
$$\alpha\phi=(M\phi-\phi_{50})/\sigma\phi, \quad \alpha_2\phi=\{(\phi_5+\phi_{95})/2-\phi_{50}\}/\sigma\phi,$$
$$\beta\phi=\{(\phi_{95}-\phi_5)/2-\sigma\phi\}/\sigma\phi$$

Here, $\phi_5$, $\phi_{16}$, ····, $\phi_{95}$ are the $\phi$ values of the percentiles, or the size associated with the percentage values on the cumulative curves. The values of these parameters are listed in Table 2.

The results of the mechanical analyses of the "Shirasu" are summarized as follows:

1) The median diameters vary within a range of $-0.6$ to 2.9 in $\phi$ scale, but those

of specimens nos. 1, 2, 5, 6, 7, 9, 11, 12 and 13 are in a range of 1.0 to 1. 7. 2) Specimens nos. 1, 2, 5, 6, 7, 11, 12 and 13 were collected from the upper and middle (the main parts) of the “Shirasu”. The size characteristics of these specimens are quite similar to each other. Each has a main mode on the size of 0 to 2 and a sub-mode on the size of $-2$ to $-5$. 3) Specimens nos. 8, 9 and 10 were collected from the lower part of “Shirasu”. The size characteristics of them are somewhat different from those of the specimens of the upper and middle parts. Specimen no. 9 has a remarkable sub-mode in the coarse fractions. On the other hand, specimens nos. 8 and 10 have no sub-mode. The main mode of each specimen, nevertheless, is on the size about 2 in $\phi$ scale. 4) Specimen no. 3 is coarser than other specimens, and the value of $Md\phi$ is $-0.57$. This may be due to its remarkable sub-mode in the coarse fractions. 5) Specimen no. 4 has somewhat different size characteristics, it has a main mode on the size of 4 in $\phi$ scale and a remarkable sub-mode in the size of $-3$ to $-2$. 6) The sorting is rather bad as the values of $\sigma\phi$ are 2.0 to 4.0. Tailing-out of both the coarser and finer fractions are found in every case. 7) The degree of skewness varies widely, as the values of $\alpha\phi$ are $-0.26$ to 0.33. 8) The values of $\beta\phi$, the parameter of kurtosis, are 0.5 to 1.3.

In general, the “Shirasu” has similar size characteristics to those of the pumice flow deposits of Mt. Asama, and also those of the “Older Pumice” of Crater Lake Region. The size characteristics of “Hai-ishi” of Mt. Aso show similar feature. These facts are recognized obviously in the diagram of cumulative curves plotted on the normal probability paper (Fig. 6). The size characteristics of these deposits may present the typical feature of the mechanical composition of pumice flow deposits.

# ——所　　報——

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# BULLETIN

OF THE

# EARTHQUAKE RESEARCH INSTITUTE

UNIVERSITY OF TOKYO

VOL. 37

1959

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東京大学

# 地震研究所彙報

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昭和35年1月25日印刷
昭和35年1月30日発行

東京都文京区本富士町一番地
東京大学構内
編纂兼
発行者　東京大学地震研究所

東京都新宿区山吹町一八四番地
印刷者　笠井康頼

東京都新宿区山吹町一八四番地
印刷所　株式会社国際文献印刷社

**売捌所**
東京都中央区日本橋通二丁目六番地
**丸善株式会社**

Sold by Maruzen Co., Ltd., Nihonbashi-dôri, Chûô-ku, Tôkyô.
Price of this copy: 330 Yen. (Postage exclusive.)

BULLETIN OF

THE EARTHQUAKE RESEARCH INSTITUTE

UNIVERSITY OF TOKYO

**Vol. 37, Part 4. December, 1959.**

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